42nd International Workshop on High-Energy-Density Physics with Intense Ion and Laser Beams

January 31st – February 4th, 2022

via Zoom

Photo: G. Otto/GSI

P r o g r a m

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Status of the FAIR Project and Perspectives for Research

Paolo Giubellino (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The construction of the FAIR facility has significantly progressed in the recent year, despite restrictions imposed by the Covid-19 Pandemic. A major milestone has been reached in early summer 2021, when the concrete work for the SIS100 ring tunnel was closed. Mounting of the technical building infrastructure will start early this year, followed by the stepwise installations of the accelerator and experiment components. Following the current schedule, the first experiments, including the commissioning of the plasma physics cave at FAIR, can commence from 2025 on, initially with SIS18 beams from GSI. The FAIR SIS100 synchrotron, providing particle beams of previously unparalleled intensity and quality, should be available from 2027 on. It will open up unprecedented research opportunities for the FAIR science community, in particular also for production and study of high-density matter. Until then, the plasma physics community, which has organised itself in the HED@FAIR collaboration, has been and continues to be extremely active and successful in performing state of the art experiments in the framework of the FAIR Phase-0 program, utilizing the ion beams from UNILAC and SIS18, together with the Phelix laser beams, and benefitting from the sophisticated instrumentation available or under preparation for dense plasma diagnosis at FAIR.

Accelerator Performance Overview, Schedule, Plans

Peter Spiller (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The presently achieved beam parameters and opportunities for accelerator improvements relevant for plasma physics experiments will be presented. Major intensity differences between experiments at HHT and APPA, can be expected by the transition to low charge state heavy ion beams. Specific issues and limitations of low charge state operation and further upgrade options will be discussed. The schedules for completion of the HEBT system towards FAIR-APPA and SIS100, indicate the expected start of the experimental program in the APPA cave.

HED@FAIR Collaboration Status and Future Plans

Alexander Golubev (ITEP)

The High-Energy-Density Science Collaboration at FAIR (HED@FAIR) will utilize the World's highest intensity relativistic beams of heavy nuclei to create and investigate highly energetic and dense-plasma states of matter. Four principal themes of research have been identified by the HED@FAIR Collaboration: Properties of materials driven to extreme conditions of pressure and temperatures, Shocked matter and material equation of state (EOS), Basic properties of strongly-coupled plasma and Warm-Dense Matter, and Nuclear Photonics with a view to the excitation of nuclear processes in plasmas, laser-driven particle acceleration, and neutron production. Collaboration research will develop over the next decade as the FAIR project is completed and the heavy ion beam and experimental capabilities evolve.
In the talk the latest progress of our collaboration concerning the construction experimental area and last results of the beam times in 2021, plans on the beam times on this year and further plans on

the early science experiments at FAIR in the APPA cave by using beam from SIS-18 accelerator will be presented.

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

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

At the site of the Gesellschaft fuer Schwerionenforschung (GSI) in Darmstadt, the Facility for Antiproton and Ion Research (FAIR) is currently under construction. FAIR will offer unique high-intensity heavy ion beams and high-intensity proton beams for experiments covering many fields of research, including the study of high-energy density samples and the study of warm dense matter.
The research in this field is coordinated by the High Energy Density Science at FAIR (HED@FAIR) collaboration, which will focus on four main fields of study: (1) The study of the properties of materials driven to extreme conditions of pressure and temperature; (2) The study of shocked matter and of equations-of-state; (3) The study of basic properties of strongly-coupled plasma and warm dense matter; and (4) Nuclear photonics, including the excitation of nuclear processes in plasmas and laser-driven particle acceleration and neutron production.
The SIS-100 heavy ion synchrotron at FAIR will provide heavy ion beams with up to $5 \cdot 10^{11}$ U^{28+} ions with 2 AGeV in a 50 ns bunch for plasma physics experiments where they will be used either to isochorically heat macroscopic samples to eV temperatures or to indirectly compress them to megabar pressures. In addition, SIS-100 will also high-energy protons (up to 10 GeV with up to $2.5 \cdot 10^{13}$ protons per bunch) which will be used for a proton microscope.
Experiments using the SIS-100 heavy ion synchrotron are scheduled to start in 2025. Before the start of FAIR, experiments are already using the upgraded UNILAC and SIS-18 accelerators at GSI ("Phase 0"). In my presentation I will give an overview of the experimental facilities that will be available for HED experiments at FAIR, as well as the current status and the timeline for the construction and commissioning of the experimental setups.

PHELIX Update and the Newly Established High-Energy-Laser Capability at the HHT Experimental Cave at GSI

Zsuzsanna Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The implementation of the high-energy laser beamline guiding the long-pulse (nanosecond) beam of PHELIX to the HHT experimental cave at GSI has recently been completed. In a first commissioning experiment we successfully demonstrated the synchronization of the ion pulse coming from the heavy-ion synchrotron with the PHELIX laser pulse to better than 10 ns at the HHT target chamber. In a second experiment using only the PHELIX pulse at HHT we showed its capability for generating X-rays in the few keV range. With this infrastructure, new diagnostic methods for the investigation of heavy-ion heated states of matter are now available, such as X-ray diffraction, X-ray Thomson scattering, imaging or spectroscopy.

After a brief update on the status and development at PHELIX itself, we will report on the results of the commissioning experiments of the PHELIX-HHT beamline.

X-Ray Probing of Ion-Beam Heated Iron

David Riley (QUB), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), V. Bagnoud, Steven White (Queen's University of Belfast)

In this talk, I will outline the basis of an upcoming experiment using the PHELIX laser in conjunction with the GSI ion-beam facility. The motivation of the experiment, is to observe structural changes in iron foils heated to up to 2000 K by the ion beam, over sub-microsecond timescales. We will use X-diffraction, where the PHELIX laser is used to generate the short-pulse Cr He-alpha X-ray source at 5.6 keV. As the foil heats we will look for changes in the crystalline structure, in particular we will look for changes to the gamma-phase (fcc) of iron from the ambient alpha-phase (bcc) and evidence of melting.

Investigation of Carbon Isochorically Heated by Intense Heavy Ion Beams Using in Situ X-Ray Diffraction and Spectrally Resolved X-Ray Scattering

Dominik Kraus (University of Rostock, HZDR)

The FAIR facility will enable world-unique capabilities to explore high energy density states by isochoric heating of samples with intense heavy ion beams. In preparation for these experiments, the HHT endstation of GSI now allows isochoric heating with limited ion beam intensity in combination with the PHELIX laser as bright X-ray backlighter. Here we present first results from a platform developed to investigate carbon under the influence of intense heavy ion beams. In situ X-ray diffraction allows for resolving the disintegration of crystal lattices while spectrally resolved X-ray scattering is used to determine the amount of disorder which, in combination with ab initio simulations, provides access to the bulk sample temperature. This measurement will be compared to optical pyrometry from the emitting surface to particularly investigate the dynamics of local melting and graphitization of diamond samples.

PRIOR Status Report

Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The PRIOR (Proton Microscope for FAIR) facility will use 2-5 GeV intense proton beams from SIS-18 or SIS-100 synchrotrons and will allow for a significant step forward in spatial and temporal resolution. In 2014, a PRIOR prototype (PRIOR-I) based on high-gradient permanent magnet quadrupole lenses has been constructed at the HHT area of GSI and used in static and dynamic experiments. In 2020, the final version of the PRIOR microscope (PRIOR-II) which employs small but strong and radiation-resistant

electromagnets has been successfully commissioned at GSI as well.
In this paper we give an overview of the PRIOR project, discuss the results achieved so far and outline the project plans for upcoming experiments at GSI and FAIR.

Shock Compressed Non-Ideal Plasma for Proton Radiography at FAIR

Nikolay Shilkin (IPCP), Dmitry Nikolaev (IPCP), Victor Mintsev (IPCP), Alexey Kantsyrev (NRC "Kurchatov institute" - ITEP), Anton Bogdanov (NRC "Kurchatov institute" - ITEP), Vsevolod Panyushkin (NRC "Kurchatov institute" - ITEP), Alexey Skoblyakov (NRC "Kurchatov institute" - ITEP), Dmitry Kolesnikov (NRC "Kurchatov institute" - ITEP), Roman Gavrilin (NRC "Kurchatov institute" - ITEP), Alexander Golubev (NRC "Kurchatov institute" - ITEP)

Possible experiments on investigation of equation of state of a non-ideal plasma by proton radiography at FAIR are discussed. The main aim of these experiments is a direct measurements of the density of shock-compressed plasma of inert gases. Compact explosive generators developed for proton radiography are described. Details of related experiments performed at the proton microscope PUMA are discussed.

Application of Intense Ion Beams to Planetary Physics Research at the FAIR Facility

Naeem Ahmad Tahir (GSI, Darmstadt), A. Shutov, P. Neumayer, V. Bagnoud, A.R. Piriz, S.A. Piriz, C. Deutsch

LAPLAS is an important experiment that will be carried out at the Facility for Antiprotons and Ion Research (FAIR), within the framework of the High Energy Density (HED) physics program named HEDP@FAIR. This experiment is related to planetary physics research. Extensive theoretical work that includes analytic modeling and detailed numerical simulations, has been done to study the feasibility of the FAIR heavy ion beam to produce planetary core conditions in the laboratory. In the present talk we report 2D hydrodynamic simulation results to determine the minimum length of the LAPLAS cylindrical target for which the 1D hydrodynamic model in the radial direction is valid. This study is important because a shorter target is better from the diagnostic point of view. We also present an overview of this experimental scheme.

On Perspectives of HED@FAIR Experimental Study of Dual Unexplored Phenomenon - Anomalous Thermodynamics Regions Nearby Entropic Phase Transitions

Igor Iosilevskiy (Joint Institute for High Temperature (Russian Academy of Science))

In this talk we continue discussion of fundamental unexplored physical phenomenon, which could be (and should be) explored with using facilities like FAIR, NICA etc for thermophysical investigations [1,2]. The main pair of proposed objects of such investigations are (a) anomalous thermodynamics regions (ATR) accompanying (b) entropic phase transitions (S-PT). Remarkable feature of ATR and S-PT [3] is simultaneous negativity (against the usual positivity) for great number of second cross derivatives of thermodynamic potential (e.g. Helmholtz free energy F(V,T,N) etc). In application to the HED@FAIR problem the negativity of two isochoric derivatives: pressure/temperature one - $(\partial P/\partial T)V$ and pressure/energy one - $V(\partial P/\partial U)V$ (Gruneizen) lead to non-standard sequence of expansion and compression of isochorically heated sample via HIHEX scheme. Second, anomalous negative isentropic termal/pressure derivative $(\partial T/\partial P)S$ leads to (i) non-standard behavior of temperature under isentropic compression via LAPLAS scheme, i.e. anomalous T-decreasing instead of usually expected T-increasing; and, on the contrary, (ii) T-increasing instead of expected T-decreasing along isentropic expansion in second (release) stage of HIHEX scheme. In our talk we base our analysis on two examples of discussing combinations of anomalous thermodynamics region (ATR) and entropic phase transitions (S-PT) , which are predicted by so-called First-Principle Equation of State (FPEOS)(see e.g. [4]), as well as by modeling EOS (code SAHA [5]), in application to two materials: hot dense nitrogen and hydrogen (deuterium). In both the cases we discuss calculated parameters of the two conjugated objects, S-PT & ATR, as well as the hypothetical resulting thermo- and hydrodynamic anomalies within dynamic processes in HIHEX and LAPLAS scheme.

1. Iosilevskiy I.L. Oral talk at Hirschegg-2021
2. Nikolaev D.N. Oral talk at Hirschegg-2021
3. Iosilevskiy I.L. Oral talks at Hirschegg-2013, 2017, 2019.
4. Driver K., Militzer B., Phys. Rev. B, V.93, 064101 (2016)
5. Gryaznov V., Iosilevskiy I., J. Phys. A: Math. Theor. V.42, 214007 (2009)

Tuesday (February 1st)

Start	Duration	Speaker	Title
Session 4: HED Facilities and Research Overviews (Chair: Zsuzsanna Major)			
08:30	00:30	TONCIAN, Toma	Studying relativistic plasmas using the ReLaX laser at HED
09:00	00:30	BLIKOV, Anton	RFNC-VNIEF: Extreme States of Deuterium and Helium Plasmas at the Pressures up to 20 TPa
09:30	00:30	LÜTGERT, Julian	Probing the Opacity in the Interior of Red Dwarfs at NIF
10:00	**00:20**	**Coffee break**	
Session 5: Laser Particle Acceleration and Applications (Chair: Stefan Karsch)			
10:20	00:30	ROSMEJ, Olga	Ultra-Bright Sources of MeV Particles and Radiation Based on DLA Electrons
10:50	00:20	HORNUNG, Johannes	Laser-Proton Acceleration Scaling at PHELIX Using Regimes of Equal Laser Power
11:10	00:30	ZIMMER, Marc	Demonstration of Non-Destructive Material Characterization at a Laser-Based Neutron Source
11:40	00:20	GEULIG, Laura	Update on the Laser-Driven Heavy Ion Acceleration at CALA
12:00	00:20	MILLÁN CALLADO, Maria	Multi-Shot Characterization of a Laser-Driven Neutron Source at the PW DRACO Facility
12:20		**Lunch break**	
Session 6: HED and LPA Research Highlights (Chair: Juan Fernández)			
17:00	00:30	ZYLSTRA, Alex	Megajoule fusion yield produced from inertial fusion implosions at the National Ignition Facility
17:30	00:15	SHAW, Jessica	Developments in the Development of the OMEGA Electron Radiography HED Diagnostic – Part I
17:45	00:20	FREEMAN, Matthew	Developments in the Development of the OMEGA Electron Radiography HED Diagnostic – Part II
18:05	00:30	SCHENKEL, Thomas	Proton and Ion Pulses from Laser-Plasma Acceleration for Surface Modification and Doping of Semiconductors
18:30			**End of Day**

Studying Relativistic Plasmas Using the ReLaX Laser at HED

Toma Toncian (HZDR)

High-energy and high-intensity lasers are essential for pushing the boundaries of science. Their development has allowed leaps forward in basic research areas including laser-plasma interaction, high-energy density science, metrology, biology and medical technology. The HiBEF user consortium contributes and operates two high-peak-power optical lasers at the HED instrument of the European XFEL facility. These lasers will be used to generate transient extreme states of density and temperature to be probed by the X-Ray beam. This contribution introduces the ReLaX laser, a short-pulse high-intensity Ti:Sa laser system, and discusses its characteristics as available for user experiments. As the outcome of internal commissioning experiments, we will as show unprecedented synchronization results for a 100 TW class laser and will validate the performance as laser-plasma driver with relativistic I > $10^{20} W/cm^2$ intensity on target by investigations of TNSA as laser-proton acceleration mechanism. Additionally, we have investigated the effect of EMP and laser generated secondary radiation and particle sources on several x-ray diagnostics, and have developed successful strategies to reduce their impacts. The commissioning of ReLaX is concluded by the successful run of the first user experiment "HED 2621: User community assisted commissioning of the UHI Laser at HED, impact of relativistic plasma environment on x-ray diagnostics". The main goal of 2621 was to validate SAXS, PCI and x-ray spectroscopy on a variety of targets covering a multitude of science cases such as, hole boring, relativistic transparency, fast electron transport along extended target, isochoric heating of buried targets, EOS determination by shocked targets, plasma instabilities in relativistic intensity regime.

Extreme States of Deuterium an Helium Plasmas at the Pressures Up to 20 TPa

Anton Blikov (RFNC-VNIIEF), Mikhail Mochalov (RFNC-VNIIEF), Radiy Il'kaev (RFNC-VNIIEF), Sergey Erunov (RFNC-VNIIEF), Vladimir Arinin (RFNC-VNIIEF), Vladislav Komrakov (RFNC-VNIIEF), Igor Maksimkin (RFNC-VNIIEF), Vladimir Ogorodnikov (RFNC-VNIIEF), Andrey Ryzhkov (RFNC-VNIIEF)

Presented the recent experimental results on the compressibility of nonideal deuterium and helium plasmas quasi-isentropically compressed to pressures 20 TPa in devices of spherical geometry. The trajectories of the plasma-compressing metallic shells were recorded by means of powerful pulsed X-ray sources (betatrons and a linear high-current accelerator) with a penetrability up to 250 mm of lead. Plasma densities up to 14 g/cc were determined from the measured radius of the shell at the instant of its "stopping". Plasma pressure was derived using gas-dynamic computations including the real parameters of the experimental devices.

Probing the Opacity in the Interior of Red Dwarfs at NIF

Dominik Kraus (HZDR), Julian Lütgert (HZDR)

We have developed an experimental platform at the National Ignition Facility for specifically tailored spherical implosions to compress hydrogen to extreme densities (up to ~ 800× solid) at moderate temperatures (T~ 800 eV), i.e. to conditions, which are relevant to the interiors of red dwarfs. The dense plasma is probed by laser-generated X-ray radiation of different photon energy to determine the plasma opacity due to collisional (free-free) absorption and Thomson scattering. The obtained results benchmark radiation transport models, which in case for free-free absorption show strong deviations at conditions relevant to red dwarfs. This very first experimental test of free-free opacity models at these extreme states will help to constrain where inside those celestial objects energy transport is dominated by radiation or convection. Moreover, our study will inform models for other important processes in dense plasmas, which are based on electron-ion collisions, e.g. stopping of swift ions or electron-ion temperature relaxation.

Ultra-Bright Sources of MeV Particles and Radiation Based on DLA Electrons

Olga Rosmej (GSI, Darmstadt)

Short overview of experimental campaigns at the PHELIX laser will be given with the focus on applications of high-current DLA electrons. Literature:

1. M. M. Günther, O.N. Rosmej, P. Tavana, M. Gyrdymov, A. Skobliakov, a. Kantsyrev, S. Zähter, N.G. Borisenko, A. Pukhov, and N.E. Andreev, “Prospective insights in laser-generated ultra-intense gamma-ray and neutron sources for nuclear applications and science”, Nature Communications (2021) accepted.
2. O. N. Rosmej, X. F. Shen, A. Pukhov, L. Antonelli, F. Barbato, M. Gyrdymov, M. M. Günther, S. Zähter, V. S. Popov, N. G. Borisenko, and N. E. Andreev, Bright betatron radiation from directlaser-accelerated electrons at moderate relativistic laser intensity, Matter Radiat. Extremes 6, 048401 (2021); https://doi.org/10.1063/5.0042315
3. X. F. Shen, A. Pukhov, M. M. Günther, and O. N. Rosmej, Bright betatron x-rays generation from picosecond laser interactions with long-scale near critical density plasmas, Appl. Phys. Lett. 118, 134102 (2021); https://doi.org/10.1063/5.0042997
4. O N Rosmej et al, “High-current laser-driven beams of relativistic electrons for high energy density research”, Plasma Phys. Control. Fusion 62 (2020) 115024 (15pp) https://doi.org/10.1088/1361-6587/abb24e
5. Rosmej, O.N. et al., “Interaction of relativistically intense laser pulses with long-scale near critical plasmas for optimization of laser based sources of MeV electrons and gamma-rays”, New J. Phys. 21 (2019) 043044 https://doi.org/10.1088/1367-2630/ab1047.

Laser-Proton Acceleration Scaling at PHELIX Using Regimes of Equal Laser Power

Johannes Hornung (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Yannik Zobus

Comparing the scaling of the maximum reachable energy of laser-accelerated protons for various laser parameters is still challenging, especially considering the outcome of different laser facilities. It is typically necessary to use experimental data from different laser systems to cross-check empirical and theoretical scalings, since the parameter space is usually not fully covered by a single laser system. Here, we map the widest possible range of parameters of the PHELIX laser system by presenting a study on proton-acceleration at PHELIX for a wide range of on-target laser power from 5 TW up to 200 TW. We vary the power by simultaneously changing the laser pulse duration between 0.5 ps and 13 ps and laser energy on-target between 2 J and 120 J to observe proton acceleration along different regimes of constant laser power. In addition, we also check the corresponding scaling with laser intensity, estimated with the recently installed PEtawatt TArgetarea Sensor (PETAS) to gather information about the on-shot intensity at the target position. We measure the corresponding energy of the accelerated protons with Radiochromic film stacks, as well as a high-resolution Thomson-parabola [1] and compare the resulting energies with scalings from various literatures [2,3].

[1] N. Schroeter, Development and calibration of a high-dispersive Thomson parabola for laser-driven ion beams. Masterarbeit, Technische Universität Darmstadt, 2017.

[2] K Zeil et al, The scaling of proton energies in ultrashort pulse laser plasma acceleration New J. Phys. 12 045015, 2010

[3] M. Zimmer et al, Analysis of laser-proton acceleration experiments for development of empirical scaling laws, Phys. Rev. E 104, 045210, 2021

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

Marc Zimmer (Technische Universität(TUDA))

Compact laser-based neutron sources have attracted great interest in the last years due to a growing field of applications. Neutrons interact via the nuclear force which results in relatively large penetration depths and isotope specific interaction cross-sections. This can be used to identify the isotopic composition of samples. This allows applications like the inspection of cargo containers for fissile material or explosives as well as the tracing of artifacts to their geological origin. While conventional neutron sources such as reactors and spallation sources are large in size, expensive and produce strong background radiation with large pulse widths, it is more desirable to have compact neutron sources with short pulse lengths which require less shielding. Laser-based neutron sources can fill this gap in the near future when modern high repetition rate laser systems can be used. In addition, the short neutron pulse length in the order of one nanosecond facilitates new applications such as neutron resonance spectroscopy and neutron resonance imaging.

Here, we present recent results from experimental campaigns at the PHELIX laser system at the GSI Darmstadt. In the experiment, protons and deuterons have been accelerated from thin foils up to 50 MeV. These ions were converted by nuclear reactions inside a catcher material into 10^{10} neutrons per shot which were subsequently moderated down into the eV regime. With this epithermal neutron beam, it was possible to identify several isotopes inside a 2.7 mm thick sample using neutron resonance spectroscopy. In addition, laser-driven thermal neutron radiography was applied for measuring the thickness of indium cadmium plates behind a lead shielding. Also, the first demonstration of neutron resonance radiography will be presented. I will further give an outlook for future applications that will be enabled by high repetition rate laser systems and liquid leaf targets.

Laser-based neutron sources will be developed and applied at the international center for nuclear photonics at the TU Darmstadt in close cooperation with their industrial partner Focused Energy GmbH.

Update on the Laser-Driven Heavy Ion Acceleration at CALA

Laura Desiree Geulig

We report on the current work on laser driven heavy ion acceleration at the Centre for Advanced Laser Applications (CALA), using the ATLAS 3000 laser with a central wavelength of 800 nm, a pulse length of about 25 fs and currently up to 8 J energy on target in the context of developing the novel 'fission-fusion' nuclear reaction mechanism [1]. In a first step, the efficient acceleration of gold ions with kinetic cutoff-energies above 7 MeV/u is targeted.
For our experiments the laser is directed to a dedicated beam line and focused with an f/2 parabola on gold foils with thicknesses ranging from 100 nm to 500 nm. In order to analyze the accelerated ion bunch, a special Thomson Parabola Spectrometer was designed that resolves the full proton and gold spectrum as well as the individual, high gold charge states [2]. A radiative heating system is integrated into the setup to enhance the acceleration of gold ions by removing hydro-carbon surface contaminations. An integrated IR spectrometer allows for in-situ measurement of the heated foil temperature, while enabling a simultaneous monitoring with a camera to detect possible thermal damage to the foil [3]. With the current setup, proton cutoff energies above 21 MeV have already been realized, while the integration of the detection system for heavy ions is still ongoing.

[1] D. Habs et al., Appl. Phys. B 103, 471-484 (2011)
[2] F.H. Lindner et al., arXiv:2104.14520, submitted to Scientific Reports (2021)
[3] M. Weiser, Master Thesis, LMU Munich, 2021

Multi-Shot Characterization of a Laser-Driven Neutron Source at the PW DRACO Facility

María de los Ángeles Millán Callado (Universidad de Sevilla (US), Dpt. Física Atómica, Molecular y Nuclear (FAMN), Seville, Spain - Centro Nacional de Aceleradores (CNA, US - Junta de Andalucía - CSIC), Seville, Spain)

The development of ultra-fast ultra-high-power lasers opens the door to a vast number of research fields and applications. Among others, the use of lasers as compact ion sources makes them a promising alternative to conventional accelerators for the production of proton, deuteron and neutron beams. The potential applications of laser-driven neutron sources (LDNS) rely on the performance of nuclear physics detectors in the environment produced by the laser-plasma interaction which affects the detector's behavior. For this purpose, factors such as the electromagnetic noise, pile-up, background conditions, etc., should be under control before planning any nuclear physics measurement with a laser-driven neutron source.

This work summarizes preliminary results of an experimental campaign developed in autumn 2021 at the DRACO PW laser system at the Helmholtz Centre Dresden Rossendorf (HZDR). The objective of the campaign was to test and optimize conventional nuclear physics detectors for nuclear physics experiments in the harsh environment of a LDNS. To achieve this goal, a set of different detectors were used: three types of fast plastic detectors for fast neutrons, two diamond detectors for single signals of fast neutrons, and a Li-glass detector for thermal and epithermal neutrons. Different neutron production setups were tested in a typical pitcher-catcher setup combining different pitchers (deuterated and non-deuterated targets), catchers (Cu, LiF and polyethylene) and a moderator. The setup was complemented with an array of bubble detectors to monitor the neutron dose achieved in each setup.

While previous works on neutron production and detection have been performed either at high repetition rate but low (tens or at most hundreds of TW) laser power, or at high power (PW) but in single-shot; at DRACO we have succeeded in producing high repetition neutron beams in a high-power 1 PW system. With 150 shots/day delivered in a few hours, statistical analysis can be applied to characterize the resulting neutron source. This allows a systematic study of the behavior as well of the different detection systems. Last, the production of a high-frequency beam allowed using a low efficiency detector such as diamond for measuring detector signals corresponding to individual fast neutron interactions, which is the first step towards neutron induced reaction experiments at a LDNS.

Megajoule Fusion Yield Produced From Inertial Fusion Implosions at the National Ignition Facility

Alex Zylstra (Lawrence Livermore National Laboratory)

Thermonuclear fusion in the laboratory is a scientific grand challenge, a highly compelling problem because the fusion reactions can self-heat the fuel and continue the burn.
Predominantly approaches use the fusion of deuterium and tritium nuclei, which generates 17.6 MeV of energy released in a neutron and alpha particle. The alpha particle, which carries 1/5 of the energy, can heat the plasma. A plasma in which the alpha self-heating is greater than external heating is termed a 'burning plasma', and one in which the self-heating dominates over all loss mechanisms, leading to a run-away increase in temperature, is termed 'ignited'.
Inertial confinement fusion (ICF) has pursued these scientific milestones using large laser drivers, notably the National Ignition Facility (NIF) at LLNL. Here we use the laser energy, up to 1.9MJ, to generate a hot x ray bath, which creates ablation pressures of hundreds of Mbar at the outer surface of a fuel-containing capsule. The ablation pressure implodes the capsule, with fuel pressures of several hundred GBar generated as the fuel stagnates at the center. The combination of these extreme pressures and inertial confinement times from the surrounding material can lead to burning and ignited plasmas. Recent experiments on NIF in the last year have generated 25x higher fusion yields than previous records, up to 1.3MJ. The physical basis for this increase in performance relative to previous NIF results, as well as the scientific implications, will be discussed. The substantially higher level of fusion self-heating in these plasmas generates unprecedented conditions for experiments in

the laboratory.

*Work performed under the auspices of the U. S. Department of Energy by LLNL under contract DE-AC52-07NA27344. LLNL-ABS-828872

Developments in the Development of the OMEGA Electron Radiography HED Diagnostic

Matthew Freeman (Los Alamos National Laboratory), Jessica Shaw (University of Rochester)

Recent results using the laser-driven Self-Modulated Laser Wakefield Accelerator (SMLWFA) at OMEGA EP at the Laboratory for Laser Energetics will be shown. Each flash radiograph is acquired with 4 × 10^{12} polychromatic electrons. A spatial resolution of 75 µm across an areal density range from 7 mg cm^{-2} to 3 g cm^{-2} was demonstrated, with objects placed flat against a detector. A resolution pattern was placed in a ×3 projection configuration demonstrating XXX µm spatial resolution. Potential future work with an energy-selection collimator and magnetic lens system will be described. Ultimately this technique may be turned into an ICF probe with 10 µm or better spatial resolution.

Proton and Ion Pulses From Laser-Plasma Acceleration for Surface Modification and Doping of Semiconductors

Thomas Schenkel (Lawrence Berkeley National Laboratory)

We report on ion acceleration experiments conducted at the BELLA Center and at PHELIX where pulses of laser-plasma accelerated protons and ions where used to irradiate silicon and diamond samples. Proton and heavier ion pulses (e. g. boron, carbon and titanium) of varying intensities (up to 10^{12} ion/shot/cm^2 on target) irradiated samples. Protons pre-heat samples and heavier ions canbe implanted into a hot target (depending on the flight time differentials between protons and heavier ions and the target cooling rate). We quantify the flux of lower energy ions through depth profiling after pulsed ion implantation into silicon wafers. A Thomson parabola or Faraday Cup were used for in situ characterization of ion pulses, complementing ex situ analysis. Intense proton and ion pulses excite and heat targets, leading to exfoliation, formation of specific defects (e. g. color centers) and doping of materials depending on details of the proton and ion flux. We discuss opportunities for materials processing and qubit synthesis with intense ion pulses from laser-plasma acceleration.
The work is supported by the U.S. Department of Energy Office of Science, under Contract No. DE-AC02-05CH11231.

Wednesday (February 2nd)

Start	Duration	Speaker	Title
Session 7: Laser-Driven Particle Acceleration (LPA) and Applications (Chair: Christian Rödel)			
08:30	00:30	SCHRAMM, Ulrich	High Dose-Rate Irradiation with Laser Accelerated Proton Beams – Prerequisites and Pilot Study Results
09:00	00:20	ANDREEV, Nikolay	Laser-Driven Ultra-Relativistic Electrons for High Energy Density Research
09:20	00:20	KARSCH, Stefan	Hybrid LWFA-PWFA: A Stability and Beam-Quality Booster Laser-Generated Electron Beams
09:40	00:20	SAVEL'EV, Andrey	Low Divergent High Charge Electron Beams Laser Acceleration from Subcritical Plasma
10:00	00:20	SHEN, Xiaofei	Cross-Filament Stochastic Acceleration of Electrons in Kilojoule Picosecond Laser Interactions with Near Critical Density Plasmas
10:20	00:30	CERNAIANU, Mihail	Recent results on the ion acceleration commissioning experiment at 1 PW level in ELI-NP
10:50	**00:20**	**Coffee break**	
Session 8: WDM and Condensed Matter Research (Chair: Ronald Redmer)			
11:10	00:20	TKACHENKO, Igor	Static and Dynamic Properties of Warm Dense Matter
11:30	00:20	FEDOROV, Ilya	Exciton Mechanism as a Physics Model of Warm Dense Hydrogen Metallization
11:50	00:20	SCHÖRNER, Maximilian	Ab Initio Simulations for the Ion-Ion Structure Factor of Warm Dense Aluminum
12:10	00:20	PREISING, Martin	Nonmetal-To-Metal Transition in Dense Fluid Helium
12:30	00:20	FILLPOVIC, Marko	Study of QED Effects in Collision of Near-Surface Accelerated Electrons with High-Intensity Lasers
12:50		**Lunch break**	
15:00	**1:30**	**Poster Session I**	
Session 9: Laser-driven secondary sources and their applications (Chair: Thomas Schenkel)			
17:00	00:20	GÜNTHER, Marc	Strong Enhanced Laser-Driven Neutron Generation and Proton Acceleration Applicable for Nuclear Physics Applications
17:20	00:20	HESSELBACH, Philipp	Optimization of X-Ray Backlighter Sources as Diagnostics for Ion-Heated Matter
17:40	00:20	PUKHOV, Alexander	Efficient Narrow-Band Terahertz Radiation from Electrostatic Wakefields in Nonuniform Plasmas
18:00	00:20	BOLLER, Pascal	On-line detection of radioactive fission isotopes produced by laser-accelerated protons
18:20	00:20	REICHWEIN, Lars	Dipole Laser Pulses for the Acceleration of Spin-Polarized Proton Bunches
18:40			**End of Day**

High Dose-Rate Irradiation With Laser Accelerated Proton Beams - Prerequisites and Pilot Study Results

Ulrich Schramm (HZDR)

In the last two years significant progress has been made in exploiting repetition-rate capable Petawatt-scale Ti:Sapphire lasers for the acceleration of proton bunches to well beyond 60 MeV energies [1]. The achieved beam delivery performance [2] enabled first demanding applications like the in-vivo irradiation study of tumors compliant with established radiobiology protocols [3]. Further multi-beam applications [4] like ion pump - betatron radiation probe experiments of warm dense matter come into reach.
The talk will discuss the developments in laser and diagnostics capabilities at the DRACO PW laser at HZDR that lead to the advanced proton performance, present novel target schemes like fully monitored cryogenic hydrogen jets [5,6] and introduce acceleration mechanisms beyond TNSA that might allow for even higher proton energies at comparatively compact systems.

[1] T. Ziegler, et al., Proton beam quality enhancement by spectral phase control of a PW-class laser system, Sci. Rep. 11, 7338 (2021)
[2] F. Brack, et al., Spectral and spatial shaping of laser-driven proton beams using a pulsed high-field magnet beamline, Sci. Rep. 10, 9118 (2020)
[3] F. Kroll, et al., Tumor irradiation in mice with a laser-accelerated proton beam, Nature Physics in press
[4] F. Albert, et al., 2020 Roadmap on Plasma Accelerators, New Journal of Physics 23, 031101 (2021)
[5] L. Obst, et al., All-optical structuring of laser-driven proton beam profiles, Nature Commun. 9, 5292 (2018)
[6] M. Rehwald, et al, submitted (2021)

Laser-Driven Ultra-Relativistic Electrons for High Energy Density Research

Nikolay Andreev (JIHT RAS)

The efficient generation of relativistic electrons with an energy of tens of MeV in a plasma of near critical electron density was demonstrated at relativistic laser intensities. Good agreement between the experimental data and the results of the 3D-PIC simulations was obtained.
The characteristics of accelerated electrons are analyzed depending on the laser and target parameters for picosecond and femtosecond pulses. Application of the low-density polymer foams will result in a significant increase in diagnostic potential in probing of high energy density matter.

Hybrid LWFA-PWFA: A Stability and Beam-Quality Booster Laser-Generated Electron Beams

Stefan Karsch (Universität München)

Laser-wakefield accelerators have long been investigated as a possible route towards compact, high-gradient replacements for the current RF-based acceleration technology. Despite tremendous progress in terms of achievable energy (up to multi-GeV), charge (up to nC), current (100 kA) and spectral charge density (up to 20pC/MeV), LWFA-generated electron bunches have always suffered from their comparatively large spectral bandwidth, their sensitive dependence on minute fluctuations of the drive laser parameters and the failure to reach normalized emittances well below 1µm. The reasons are manifold: the interaction of intense laser pulses with plasma is subject to nonlinear instabilities, and their strong transverse fields always cause full ionization of the target gas and heats the plasma electrons. The latter intrinsically produces hot electron beams, while the former prevents the use of alternative cold injection mechanisms. While it is possible to replace the ponderomotive fields of an intense laser with the space charge field of an intense particle bunch in order to create an accelerating wakefield, up to now such research was only possible on a few large-scale accelerator facilities capable of producing kA, few-fs particle bunches as wakefield drivers in a process called particle-driven wakefield acceleration (WFA). In recent years, we could show that LWFA-generated electron bunchesfrom 100-TW-class laser facilites fulfill the required drive beam parameters for PWFA in a nearly ideal way, allowing to demonstrate wakefield generation and witness acceleration in a secondary plasma. However, the question arises whether coupling two plasma accelerators will not dramatically increase the instabilities, or has a poor efficiency. We report on recent experiments demonstrating that the PWFA process is largely insensitive to driver energy fluctuations, allowing the hybrid scheme to achieve comparable or potentially even better stability than a pure LWFA. Moreover, as a consequence the high energy transfer efficiency and a cold injection scheme in the PWFA part, the spectro-spatial charge density (and most likely the emittance) can exceed that of the a pure LWFA, giving a real-world performance boost to laser-driven electron accelerators.

Low Divergent High Charge Electron Beams Laser Acceleration From Subcritical Plasma

Andrey Savel'ev (Lomonosov Moscow State Univ.), Diana Gorlova (Lomonosov Moscow State University), Ivan Tsymbalov (Lomonosov Moscow State University), Ekaterina Starodubtseva (Lomonosov Moscow State University), Konstantin Ivanov (Lomonosov Moscow State University), Akim Zavorotny (Lomonosov Moscow State University), Ilya Tsygvintsev (Keldysh Institue of Applied Mathematics RAS)

We present experimental and numerical studies of electron acceleration in the subcritical plasma pre-formed by the nanosecond prepulse. Experiments were conducted using 2 TW 50 fs laser pulse focused up to $10^{19} W/cm^2$ intensity. The preplasma was formed by the 6-10 ns prepulse with controllable advance time with respect to the femtosecond one. Different geometries and targets were used – thick solid plates, thin 10 µm films, dense gas jets. The optimal parameters were found in each case providing for production of low divergent (less than 50 mrad) electron bunches with energies upto 10 MeV and charges of 1-2 nC/J. The photoneutron diagnostics was employed to assess the number and energy spectrum of the relativistic electron beam. The photoneutron yield modelling was made using GEANT 4 package.
The numerical simulation using the Mandor and Smiley PIC codes helped to reveal main features of the acceleration process: electron injection by the parametric instability or ionization injection followed by the DLA or combined DLA-LWFA process. The plasma formation was modelled by the

hydrodynamic simulations. We also consider the injection and acceleration processes at higher energies (peak powers) of the femtosecond pulse.

Cross-Filament Stochastic Acceleration of Electrons in Kilojoule Picosecond Laser Interactions With Near Critical Density Plasmas

Xiaofei Shen (Heinrich-Heine-Universität Düsseldorf), Alexander Pukhov (Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf), Olga Rosmej (GSI, Darmstadt), Nikolay Andreev (JIHT RAS)

The advent of kilojoule laser facilities, like NIF-ARC, LMJ-PETAL, and LFEX, opens a new regime of laser-plasma interaction. Understanding the interaction of such laser pulses with long-scale length preplasma or homogeneous near critical density (NCD) plasma is crucial for explaining the reported results and guiding future experiments.
In this talk, I will present our recent work on the long-time interaction of realistic picosecond laser pulses with large focal spots with submillimeter NCD plasmas. Using full three-dimensional particle-in-cell simulations, we demonstrate that in this regime, cross-filament stochastic acceleration is an important mechanism that contributes to the production of superponderomotive, high-flux electron beams. Since the laser power significantly exceeds the threshold of the relativistic self-focusing, multiple filaments are generated. Most of energetic electrons are no longer confined in an individual channel. They first are accelerated by the direct laser acceleration mechanism in a channel, and then may jump across into adjacent channels. This triggers the stochastic motion of electrons. As a result, electrons can be further heated up to superponderomotive energies. The effective electron temperature increases with the laser pulse duration (determining the total interaction time τ_i) as $T_{eff} \propto {}_i^{0.65}$.

Recent Results on the Ion Acceleration Commissioning Experiment at 1 PW Level in ELI-NP

Mihail Octavian Cernaianu (Extreme Light Infrastructure - Nuclear Physics(ELI-NP))

The ELI-NP (Extreme Light Infrastructure - Nuclear Physics) research facility is approaching full operational status. Last year, the commissioning of the 1 PW experimental area has been successfully performed with a TNSA experiment on proton acceleration. In this experiment, the laser beam was focused down to a spot diameter of 3.5 µm FWHM, with a peak intensity of the order of $I_0 > 10^{21} Wcm^{-2}$, and interacted with solid targets of various thicknesses and materials. The central wavelength of the laser beam was 810 nm and the laser pulse had a duration of less than 25 fs. The beam's pointing was stable at ±2 µm during a full day's run. A wide parametric scan was undertaken by shooting on different target materials and thicknesses ranging from hundreds of nm to micrometers, in a configuration without and with a plasma mirror. A wide range of laser and plasma diagnostics were deployed to characterize the laser beam and the by-products of the interaction on a shot-to-shot base. The goals and the results of the commissioning experiment will be reported.

Static and Dynamic Properties of Warm Dense Matter

Igor M. Tkachenko (Universidad Politecnica de Valencia)

The dynamic structure factor and other dynamic characteristics of Fermi liquids of charged particles (a warm dense electron gas) are studied using the self-consistent version of the method of moments [1]. The advantage of this approach is that the dynamic characteristics are expressed in terms of the static ones (the static structure factor) without any adjustment to the simulation data. In addition, the static dielectric function and other static characteristics of dense warm charged Fermi liquids are also obtained exclusively from the system static structure factor [2]. All these results are in quantitative agreement with the numerical data obtained recently by the path-integral Monte-Carlo method [3]. Perspectives of the method are outlined.

[1] Yu. V. Arkhipov et al., Phys. Rev. Lett. 119, 045001 (2017); Yu. V. Arkhipov et al., Phys. Rev. E 102, 053215 (2020).
[2] J. Ara, Ll. Coloma, I.M. Tkachenko, Phys. Plasmas, 28, 112704 (2021); ibid, “Dynamic properties of classical and quantum one-component plasmas”, Intl. Conf. on the Physics of Non-Ideal Plasmas, Dresden (Germany), September 2021.
[3] P. Hamann et al., Phys. Rev. B 102, 125150 (2020); T. Dornheim, et al., Contrib. Plasma Phys. 2021, e202100098, and references therein

Exciton Mechanism as a Physics Model of Warm Dense Hydrogen Metallization

Ilya Fedorov (Joint Institute of High Temperature RAS, Moscow Institute of Physics and Technologies), Vladimir Stegailov (Joint Institute of High Temperature RAS, Moscow Institute of Physics and Technologies, Higher School of Economics)

Insulator-to-metal transition (IMT) in fluid warm dense hydrogen (WDH) is one of the unresolved problems of the last decades. There are a large number of experiments aimed at determining thermodynamic states of this transition, but they have a large number of disagreements.
This work is the result of a rethinking of theoretical works and a search for the cause of the current disagreement between the results of theory and experiment. We go beyond the FT DFT approximation and take into account the possibility of non-adibatic energy transfer from ionic vibrations to electron excitations [1]. In this case, we have obtained the effect of the formation and dissociation of excitons in the region of the observed absorption that is associated with the phase transition [2].
The resulting mechanism allows us to explain the current disagreements between static and dynamic experiments and provides a new physics picture of the transition.

[1] Fedorov, Ilya D., Nikita D. Orekhov, and Vladimir V. Stegailov. ”Nonadiabatic effects and excitonlike states during the insulator-to-metal transition in warm dense hydrogen.” Physical Review B 101.10 (2020): 100101.
[2] Fedorov, I. D., and V. V. Stegailov. ”Dissociation of Exciton States in Warm Dense Hydrogen.” JETP Letters 113.6 (2021): 396-401.

Ab Initio Simulations for the Ion-Ion Structure Factor of Warm Dense Aluminum

Maximilian Schörner (University of Rostock)

We present an extensive description of the application of a generalized hydrodynamic model to *ab initio* simulations in the warm dense matter (WDM) regime. We calculate the intermediate scattering function for warm dense aluminum by using density functional theory molecular dynamics (DFT-MD) simulations. From this data set we derive the static and dynamic ion-ion structure factors. Applying a generalized hydrodynamic model we can fit the excitation spectra of the ion system and thereby extract the dispersion for the ion acoustic modes, and also the decay coefficients for the diffusive and collective modes. The results are discussed and compared with experimental data if available. We show that computational limitations prevent sufficient access to the hydrodynamic limit and demonstrate that this can be circumvented using machine learning.

Nonmetal-To-Metal Transition in Dense Fluid Helium

Martin Preising (Universität Rostock)

We have performed extensive molecular dynamics simulations based on density functional theory for fluid helium for densities between 1 and 22 g/cm³ and temperatures between 10 000 and 50 000 K [1] in order to characterize and locate the nonmetal-to-metal transition in P-T space. Chemical models for the equation of state and plasma composition predict a first-order phase transition known as plasma phase transition (PPT) [2], similar to the metallization in hydrogen. The results of our ab initio simulations for the equation of state, the electrical conductivity and the reflectiviy indicate that this transition is continuous for helium, without a density jump and a latent heat as characteristic of a first-order phase transition [3]. Implications for astrophysical plasmas are discussed.

[1] Preising et al., Phys. Rev. B 102, 224107 (2020)
[2] Förster et al., Laser Part. Beams 10, 253 (1992)
[3] Preising et al., Contrib. to Plasma Phys. 61, e202100105 (2021)

Study of QED Effects in Collision of Near-Surface Accelerated Electrons With High-Intensity Lasers

Marko Filipovic (Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf)

As the development of laser technology progresses, ever higher intensities and better beam qualities in laboratories become available. This advance enables new experimental setups in the study of laser-plasma interaction and quantum electrodynamic (QED) effects like quantum photon emission and pair production in extreme fields and densities.

We present two-dimensional Monte-Carlo particle-in-cell simulations of two high-intensity lasers

grazing the surface of a solid-state target. Due to the fields near the target surface electrons are extracted and accelerated. Finally, the extracted electrons collide with the counterpropagating laser, which generates a QED cascade. Here, the processes are studied for various laser intensities, angle of incidence and point of incidence at the surface.

Strong Enhanced Laser-Driven Neutron Generation and Proton Acceleration Applicable for Nuclear Physics Applications

Marc Günther (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

Ultra-intense neutron sources and accelerated ions are important tools in many research fields from nuclear and atomic science up to material science and medical as well as biophysics applications. Especially, in laboratory based nuclear astrophysics, one of the big challenges is to provide suitable astrophysical like photon and particle sources. Laser-driven sources promising a capable basis for such fundamental investigations like the r-process nucleosynthesis or nuclear fusion and fission processes. We report on an approach for providing efficient laser-driven particle sources from sub-picosecond laser pulse interactions with hydrodynamical stable and homogenous sub-mm long-scale near critical electron density (NCD) plasmas. First experiments have demonstrated a strong enhanced generation of neutrons and ion acceleration at moderate relativistic laser intensities. A boosted laser energy-to-particle efficiency was obtained, which realized record values in laser-driven particle production. Spectral properties promising applicability in nuclear astrophysics. Furthermore, the approach promises strong boost of diagnostic potential of existing kJ PW-class laser systems used in ICF research. Especially, highly forward collimated laser accelerated proton beams were observed with strongly increased maximum energies and a flat slope up to proton cut-off energy in the spectrum, far from exponential behavior. Here, we present these forward-looking insights in laser-based particle sources, which demonstrate a high capability for nuclear applications and science [M. M. Günther et al., Nature Communications (accepted for publication. Publication online, soon)].

Optimization of X-Ray Backlighter Sources as Diagnostics for Ion-Heated Matter

Philipp Hesselbach

The experimental site of GSI offers the unique possibility to conduct experiments combining intense heavy-ion beams of the SIS heavy-ion synchrotron with high-energy laser pulses from the PHELIX laser. This allows, for example, to generate mm-sized samples at extreme conditions by volumetric heating with the heavy-ion beams, while laser-produced intense X-ray sources enable advanced X-ray probing schemes.

With this perspective at GSI, we are currently exploring a variety of schemes for the generation of laser-driven X-ray sources using the PHELIX laser. The optimization of both, narrow band X-ray sources, e.g., for X-ray diffraction and Thomson scattering, and broad band sources, e.g., for X-ray absorption spectroscopy, is a major objective. This talk focuses, in particular, on a recent experiment to investigate the possibility to enhance the K-alpha yield at photon energies above 10 keV. We have investigated the scaling of the two-plasmon decay instability for different irradiation conditions and target designs and assessed its potential to increase the X-ray yield due to the generation of superthermal high-energy electrons.

Efficient Narrow-Band Terahertz Radiation From Electrostatic Wakefields in Nonuniform Plasmas

Alexander Pukhov (Uni Dusseldorf)

It is shown that electrostatic plasma wakefields can efficiently radiate at harmonics of the plasma frequency when the plasma has a positive density gradient along the propagation direction of a driver. The driver propagating at a subluminal group velocity excites the plasma wakefield with the same phase velocity.
However, due to the positive density gradient, the wake phase velocity steadily increases behind the driver.
As soon as the phase velocity becomes superluminal, the electrostatic wakefield couples efficiently to radiative electromagnetic modes. The period of time when the phase velocity stays above the speed of light depends on the density gradient scale length. The wake radiates at well-defined harmonics of the plasma frequency in the terahertz band. The angle of emission depends on the gradient scale and the time passed behind the driver. For appropriate plasma and driver parameters, the wake can radiate away nearly all its energy, which potentially results in an efficient, narrow-band, and tunable source of terahertz radiation.

On-Line Detection of Radioactive Fission Isotopes Produced by Laser-Accelerated Protons

Pascal Boller (GSI, TU Darmstadt), Alex Zylstra (LLNL), Jeffrey Burggraf (LLNL), Justin Jeet (LLNL), Lee Bernstein (LLNL), Christian Brabetz (GSI), Jan Glorius (GSI), Johannes Hellmund (GSI), Johannes Hornung (GSI), Yuri Litvinov (GSI), Vincent Bagnoud (GSI), Dieter Schneider (LLNL), Thomas Kühl (GSI, Johannes Gutenberg-Universität Mainz)

The on-going developments in laser acceleration of charged particles and the production of γ-rays and neutrons as secondary beams provide a basis for novel nuclear physics experiments. The laser-matter interaction is able to generate ultra-high fluxes of particles and radiations. These fluxes are very short in both space and time and exceed the capabilities of standard particle accelerators by orders of magnitude. They are particularly interesting in the field of nuclear astrophysics, in the medical field as well as in fusion research.
A direct application nowadays is the field of laser-driven nuclear physics. In order to perform such experiments successfully, a detector system is required to perform for example γ spectroscopy. During the laser-matter interaction a γ flash and an electromagnetic pulse are generated which can lead to signal noise or even detector failure. The protection of the used detection system against these effects is especially important for short-lived nuclides. The distance to the interaction location

can be increased to protect the system, because the intensity of the radiation decreases quadratic with the distance. Additionally, a Faraday cage can be used for shielding.
We already demonstrated a functional detection setup in a laser-driven nuclear experiment in September 2019. It was performed at the Petawatt High-Energy Laser for Heavy Ion Experiments (PHELIX) at GSI. By using laser pulses of 0.5 ps duration with energies up to 200 J, proton pulses in excess of 1022 protons with energies up to 70 MeV were achieved. These pulses were used for proton incudes fission of ^{238}U. In this experiment, an on-line detection method was applied. In this method, a gas flow in a capillary tube provided a rapid transport of the fission products over several meters to a germanium detector which is additionally shielded. Thus, the system uses the two solutions mentioned above to protect the detection setup.
We improved this method and performed it at a similar experiment in December 2021.
The performed experiments demonstrate successfully the capability of the detection method to extract and detect short-lived reaction products under the demanding experimental condition imposed by the interaction of high-power lasers with matter. While optimizations were done, the on-line method can be used in many other experiments. Thus, the detection method can be used obtain possible foster further discoveries and emphasize in this way the importance of the laser-driven nuclear field.

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

Dipole Laser Pulses for the Acceleration of Spin-Polarized Proton Bunches

Lars Reichwein (Insitut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf), Markus Büscher (Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich), Alexander Pukhov (Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf)

High-energy particle beams with spin-polarization are needed for several (future) experiments, ranging from probing the structure of the proton to quantum chromodynamics. In recent years, the acceleration of such spin-polarized beams via laser-plasma interaction has gained a lot of interest, specifically the process of magnetic vortex acceleration (MVA) for proton bunches. By means of particle-in-cell simulations, we compare the acceleration of proton bunches using a dipole laser instead of ordinarily used Gaussian beams in MVA. This setup provides highly polarized proton bunches even for high laser intensities.

Thursday (February 3rd)

Start	Duration	Speaker	Title
Session 10: Inertial Confinement Fusion (Chair: Ulrich Schramm)			
08:30	00:30	ZHAN, Wenlong	Status of HIAF and ADS
09:00	00:30	ZHANG, Jie	Plasma Characteristics of the Compression, Acceleration and Collision Processes in the Double-Cone Ignition Scheme
09:30	00:20	HOFFMANN, D.H.H.	Laser and Particle Beam Interaction with Ionized Matter and Perspectives for Fusion Energy
09:50	00:20	ZHAO, Yongtao	p11B Nuclear Reactions Initiated by Laser-Accelerated Intense Proton Beam in Boron Plasma
10:10	00:20	HORA, Heinrich	Lower Than Thermal Pressures for Laser Driven Fusion Ignition
10:30	**00:20**	**Coffee break**	
Session 11: EOS (Chair: Yongtao Zhao)			
10:50	00:20	BRET, Antoine	Strongly Magnetized Parallel Collisionless Shocks in Pair Plasmas
11:10	00:20	KHISHCHENKO, Konstantin	Equation of State for Bismuth at High Energy Densities
11:30	00:20	SPIRIN, Ivan	The Application of Synchrotron Radiation for Investigation of Detonation Excitation and Shock-Induced Particle Ejection from a Free Metal Surface
11:50	00:20	KRASIK, Yakov	Possible Applications of Underwater Electrical Wire Explosions in High Energy Density Physics
12:10	00:20	YAN, Zixiang	Scaling Law in the Velocity of Free Surface and its Applications in Experiments
12:30		**Lunch break**	
15:00	**1:30**	**Poster Session II**	
Session 12: Fusion Energy (Chair: Dominik Kraus)			
17:00	00:30	FERNÁNDEZ, Juan C.	The Grand Challenge of Inertial Fusion Energy
17:30	00:30	ROTH, Markus	Proton Driven Fast Ignition and Inertial Fusion Energy
18:00	00:20	CSERNAI, Laszlo	Developments in Nano Fusion
18:20			**End of Day**

Status of the Hiaf Accelerator Facility in China

Wenlong Zhan (Chinese Academy of Sciences, Institute of modern Physics), Jiancheng Yang (Chinese Academy of Sciences, Institute of Modern Physics)

The High Intensity heavy-ion Accelerator Facility (HIAF) is under constructed at IMP in China. The HIAF main feature is a rapid acceleration of high intensity heavy ions in the booster synchrotron ring (BRing) with the ramping rate of 12 T/s. The challenges are related to the systems injector, RF cavities, power sup-plies, vacuum, magnets, etc. Works on key prototypes of the HIAF accelerator are ongoing at IMP. In this paper, an overview of the status and perspective of the HIAF project is reported.

Plasma Characteristics of the Compression, Acceleration and Collision Processes in the Double-Cone Ignition Scheme

Jie Zhang (Shanghai Jiao Tong University)

In order to optimized the compression and collision processes of the double-cone ignition (DCI) scheme [1], a series of experiments is conducted at an irradiance of $8x10^{14} - 3x10^{15} W/cm^2$ on shell targets inside the cones at SG-II Upgrade laser facility in 2021. The drive pulse configurations of 8 laser beams are optimized to perform quasi-adiabatic compression, acceleration in the cones and efficient collision from the cone tips. Laser-plasma instabilities are found to be greatly mitigated by using large-angle irradiation with s-polarization. The angularly resolved measurements of scattered energies indicate that the total laser absorption by plasmas inside the cones can be over 90%. The energy flows inside cones are traced with optimization of hydrodynamic efficiency by matching the electron-ion collision free path with the conduction zone length. Sequence of shocks generated by the optimized drive pulse is carefully controlled to form an optimized adiabatic compression inside the cones. The density of the plasma at the tip from a single cone is measured to be about 32 g/cm^3 and the velocity of the plasma jets from the cone-tips is about 240 km/s, for a laser energy of 6 kJ from each side. The density of the colliding plasma is increased to 57 g/cm^3, corresponding to an areal density of 143 mg/cm^2. Another experiment is scheduled in the coming summer of 2022.

This work was supported by the Strategic Priority Research Program of Chinese Academy of Sciences (Grant No. XDA25000000).

Reference:
[1] J. Zhang, W. Wang, X. H. Yang, D. Wu, Y. Y. Ma, J. L. Jiao, Z. Zhang, F. Y. Wu, X.-H. Yuan, Y. T. Li, and J.-Q. Zhu, ”Double-cone ignition scheme for inertial confinement fusion,” Phil. Trans. R. Soc. A. 378, 20200015–11 (2020).

Laser and Particle Beam Interaction With Ionized Matter and Perspectives for Fusion Energy

Dieter H.H. Hoffmann (Xi'An Jiaotong University)

Intense ion- and laser beams are complimentary tools to induce High Energy Density in matter. The development of this field is intimately connected to technological advances of the field. We will give an overview of the projects in High Energy Density science that we currently address at Xi'An Jiaotong University with aspects of inertial fusion energy and due to recent developments we will address the proton-^{11}Boron fusion reaction.

P^{11}B Nuclear Reactions Initiated by Laser-Accelerated Intense Proton Beam in Boron Plasma

Yongtao Zhao (XJTU & IMP)

The study of nuclear reaction in plasma environment is of great importance for fusion sciences and astrophysics. The advent of high-intensity-pulsed laser technology enables in laboratory generating extreme states of matter and producing high-current ($10^{10} A/cm^2$), short-pulse($\sim$ps) ion beams. These advantages provide great experimental opportunities to explore the nuclear reaction dynamics at extreme condition, in which case complex and nonlinear effects are expected to occur. Here we report the measurements of proton-boron reaction induced by laser-accelerated intense proton beam in boron plasma target using XGIII laser facility.
The experimental setup was shown in Fig. 1. The dense plasma was generated by irradiating a boron-doped CHO foam sample with soft X rays from a ns laser-heated hohlraum. The energy loss of the protons, which is supposed to play important roles in nuclear reaction dynamics was measured simultaneously. Our method can be in future applied in a broad range of laboratory astrophysical studies at cosmic condition.
It was preliminarily found that the α yield initiated in plasma is generally higher than that in the cold foam. The enhancement of proton number by 2-3 order of magnitude induce 4-5 orders of magnitude enhancement of alpha particle yield for cold target.

Lower Than Thermal Pressures for Laser Driven Fusion Ignition

Heinrich Hora (University of New South Wales Sydney/Australia)

The elasto-mechanical stress tensor of Maxwell had to be extended to the plasma hydrodynamics conditions beyond the usual Euler equations. Clarification was needed against insufficient properties for approximations for petawatt-subpicosecond CPA-laser pulse for nuclear fusion ignition to arrive at gauge and Lorentz invariant solutions, what was not needed in magnetic confinement fusion. This resulted in the non-thermal confinement pressures in contrast to the very high thermal pressures in the range of very high pressures of dozens of million degrees centigrades and was seen in the nonlinear terms of the stress tensor expressing the involved nonlinear physics. The alternative is given by non-thermal pressures to avoid the thermal pressures of dozens of million degrees.

Strongly Magnetized Parallel Collisionless Shocks in Pair Plasmas

Antoine Bret (Universidad Castilla La Mancha)

Shocks waves are a ubiquitous feature of many astrophysical plasma systems, and an important process for energy dissipation and transfer. The physics of these shock waves is frequently treated/modeled as a collisional, fluid MHD discontinuity, despite the fact that many shocks occur in the collisionless regime. In light of this, using fully kinetic, 3D simulations of non-relativistic, parallel propagating collisionless shocks comprised of electron-positron plasma, we detail the deviation of collisionless shocks form MHD predictions for varying magnetization/Alfvénic Mach numbers, with particular focus on systems with Alfénic Mach numbers much smaller than sonic Mach numbers. We show that the shock compression ratio decreases for sufficiently large upstream magnetic fields, in agreement with theoretical predictions from previous works. Additionally, we examine the role of magnetic field strength on the shock front width. This work reinforces a growing body of work that suggest that modeling many astrophysical systems with only a fluid plasma description omits potentially important physics.

Equation of State for Bismuth at High Energy Densities

Konstantin Khishchenko (Joint Institute for High Temperatures RAS)

A new semiempirical equation of state for bismuth is proposed with taking into account melting and evaporation effects. Calculations of thermodynamic characteristics and the phase boundaries of solid, liquid and vapor over a wide range of densities and temperatures are carried out. Comparison of calculated results with available experimental data and theoretical predictions at high energy densities is presented. Obtained multiphase equation of state for bismuth can be used effectively in numerical modeling of processes under conditions of intense pulsed influences on the metal.

The Application of Synchrotron Radiation for Investigation of Detonation Excitation and Shock-Induced Particle Ejection From a Free Metal Surface

Ivan Spirin, Mikhail Antipov (FSUE ”RFNC-VNIIEF”), Denis Kalashnikov (FSUE ”RFNC-VNIIEF”), Konstantin Ten (Lavrentyev Institute of Hydrodynamics), Edward Pruuel (Lavrentyev Institute of Hydrodynamics), Alexey Kashkarov (Lavrentyev Institute of Hydrodynamics), Ivan Rubtsov (Lavrentyev Institute of Hydrodynamics)

The paper presents the results of experiments on the feasibility of using synchrotron radiation (SR) from wigglers installed on the VEPP-3 charged particle accelerator (INPh SB RAS, Novosibirsk) to record the dynamics of spatial distribution of matter densities during shock-wave initiation of explosives and in shock-induced dust flows. Compared to traditional sources of X-ray radiation arising from the deceleration of electrons accelerated by an electric field at the anode, SR has a higher flux intensity,

stability and coherence, a small angular divergence and exposure time, as well as a high repetition rate, which makes it possible to carry out X-ray chronography of explosive processes with high spatial and time resolutions.
In experiments on the study of shock-wave initiation of detonation, the evolution of an initiating shock wave into a detonation wave in an explosive based on HMX was studied. As a result, x-t diagrams of the propagation of wave processes were obtained, as well as the distributions of the densities of the substance along and across the investigated charge during the passage of shock and detonation waves through it.
In experiments on the study of shock-wave "dusting", we used samples of tin with different roughness. The experiments were carried out in vacuum, air, and helium at various initial pressures. The data obtained using SR are compared with the results of parallel measurements by the piezoelectric sensor and PDV method. It is shown that the SR method makes it possible to carry out multi-frame radiographic measurements of density distributions in shock-induced dust flows.
The obtained experimental data make it possible to refine and improve the mathematical models of the corresponding phenomena.

Possible Applications of Underwater Electrical Wire Explosions in High Energy Density Physics

Yakov Krasik (Physics Department, Technion), Simon Bland (Imperial college, London UK), Daniel Maler (Physics Department, Technion), Sergey Efimov (Physics Department, Technion), Alexander Rososhek (Physics Department, Technion)

The phenomena of underwater electrical wire explosion (UEWE) have been studied for over half a century. By driving large current pulses (>3×10^5 A) through single wire and wire arrays, matter at extreme conditions can be formed and studied (>10^9 Pa, >10^4 K). In recent years, vast experimental, modeling and numerical research was conducted on possible applications of UEWE in investigating exotic states of matter.
One such application is the acceleration of a flyer plate (target) realized by strong shockwaves and subsequent waterflow, generated by the underwater electrical explosion of a planar wire array. The flyer plate method is commonly used in the study of high energy density physics. In experiments various targets were accelerated to velocities of up to $\sim$1.3 km/s with energy efficiency transfer of up to $\sim$20% from the wire deposited energy. One and two-dimensional hydrodynamic modelling coupled with SESAME EOS for water, wire and target material give a satisfactory agreement with experimental results.
Another application is the generation of supersonic (up to $\sim$4 km/s) water jets by the underwater electrical explosion of cylindrical/conical wire arrays. The jet generation occurs due to extremely high pressure and density of water formed in the vicinity of the axis by imploding shockwave, inducing a cumulation effect which was qualitatively confirmed by preliminary simulations. It was shown that the velocity of the jet ejected from the array side depends on the array geometry and the thickness of the water layer above the array. The results obtained imply that a major part of the energy deposited into the array is transferred to the kinetic energy of this jet and to the axial flow of water generated by the relatively slow radial expansion of wires.
Both applications were experimentally studied using 2 pulse generators differing by their energy density deposition rate. Namely, explosion of a planar, cylindrical and conical Cu and Al wire array

were produced using a □s and sub-□s-timescale generators with stored energies of up to $\sim$6 kJ, delivering to the array a current pulse with amplitudes of up to □450 kA with rise time of $\sim$400 ns and $\sim$1 □s, respectively.

Scaling Law in the Velocity of Free Surface and Its Applications in Experiments

Zixiang Yan (HEDPS, Center for Applied Physics and Technology, Peking University)

Through nonequilibrium molecular dynamics simulations, we provide an atomic-scale picture of the dynamics of particles near the surface of a medium under ultra-strong shocks. This shows that the measured surface velocity vf under ultra-strong shocks is actually the velocity of the critical surface at which the incident probe light is reflected, and v_f has a single-peaked structure. The doubling rule commonly used in the case of relatively weak shocks to determine particle velocity behind the shock front is generally not valid under ultra-strong shocks. After a short period of acceleration, v_f exhibits a long slowly decaying tail, which is not sensitive to the atomic mass of the medium. A scaling law for v_f is also proposed, and this is further employed in a recent experiment to improve the measurement of particle velocity u as well as the equation of state.

The Grand Challenge of Inertial Fusion Energy

Juan C. Fernández (Focused Energy Inc.)

Achieving ignition and energy gain in a capsule of thermonuclear fuel in the laboratory via Inertial Confinement Fusion (ICF) remains a grand scientific and technological challenge. This is the case despite significant investment, research effort and progress over many years. Future utilization of ICF for inertial fusion energy (IFE) to feed the electrical grid adds considerable
additional challenges. As discussed in this session of the workshop, recently there has been dramatic experimental progress on ignition at the National Ignition Facility (NIF), which is generating renewed attention and increased public and private investment in IFE. To set the stage for the session, we summarize and explain key requirements and challenges for IFE. The aim is to provide a framework to understand the breadth of the field, appreciate the progress to date, and visualize the challenges remaining.

Proton-Driven Fast Ignition and Inertial Fusion Energy

Markus Roth (Focused Energy Inc./TU Darmstadt)

Fusion, the fundamental energy source in the universe and origin of almost all the matter we are made of. For decades scientists have worked on recreating the engine of the stars in the laboratory to harvest this energy source. As clean and safe energy is needed more than ever new developments have led to the rise of startup companies around the globe taking advantage of the science developed of the years and combining the results of the past with the technology of the 21st century to make

fusion energy a reality.
Focused Energy is a US/German startup supported by the TU Darmstadt and deeply embedded in the international science community. We are focusing on the concept of laser-driven inertial confinement fusion, an alternative approach to the magnetic confinement mainstream with their flagship facilities ITER and Wendelstein 7-X.
In inertial fusion energy (IFE) a pellet is compressed by powerful lasers and the thermalization of the fuel in the central spot is supposed to reach fusion conditions and yield. After decades of research this for the first time has been achieved successfully at the National Ignition Facility in the US on August 8^{th} 2021. However, this specific approach is not well suited for energy production.
In our approach, a small pellet containing a milligram of DT is directly irradiated by intense laser light and compressed to roughly 1000 times solid density. At the moment of maximum density, a burst of energetic, laser-driven ion beams is focused into a small part of the compressed fuel to rapidly rise the temperature above ignition temperature and start a bootstrap fusion reaction, which results in a supersonic burn wave consuming the fuel.
More than two decades of research have led to this path, which has recently been quoted the most promising approach in inertial fusion energy by international leaders in the field (see for example Physics Today).

Focused Energy plans to develop a demonstration facility within this decade to demonstrate ignition, burn and gain sufficient for attractive energy production based on the unique combination of high-energy and high-power lasers.

Developments in Nano Fusion

Laszlo P. Csernai (University of Bergen)

The recent revolution of lasers with increased power and shorter pulse length opens new possibilities for fusion for energy. Two ideas are taken from recent research. One is from high energy heavy ion research, that Quark Gluon Plasma (QGP) may burn (hadronize) simultaneously, i.e.
across a hyper-surface with time-like normal, without Rayleigh-Taylor instabilities. To enable this type of ignition an other new idea comes from nano-technology, that nano-antennas embedded in the target. The experimental verification of these ideas are in progress at the Wigner R.C.P. at lower, mJ, energies.
Amplification of laser light absorption is already verified. The verification of simultaneous transition in the whole volume is coming soon. The required high intensity but short (fs) laser pulse for ignition will be available at the ELI-ALPS soon, which is going to be the only such short pulse laser in Europe.

For the NAPLIFE Collaboration

Friday (February 4th)

Start	Duration	Speaker	Title
Session 13: LPA, Laser Technology and Diagnostics (Chair: Vincent Bagnoud)			
08:30	00:20	OHLAND, Jonas B.	Implementation of an On-Shot Focal Spot Optimization Loop at PHELIX
08:50	00:20	EFREMOV, Vladimir	Key physical processes during laser action in condensed and hollow silica-based optical fibers
09:10	00:20	RÖDER, Simon	Influence of the Stretcher Beam Size on the Temporal Contrast of Short Laser Pulses in CPA Laser Systems
09:30	00:20	ZOBUS, Yannik	A Millijoule Ultrafast Optical Parametric Amplifier for the PHELIX and PENELOPE Frontends
09:50	00:20	EFTEKHARI-ZADEH, Ehsan	Relativistic Interaction of Ultra-High Contrast Femtosecond Laser Pulses with low-Z Core, high-Z Shell Composite Nanowire Arrays
10:10	00:20	WEI, Wenqing	All-Optical Ultrafast Spin Rotation for Pre-Polarized Charged Particle Beams
10:30	**00:20**	**Coffee break**	
Session 14: Laser Matter Interactions (Chair: Abel Blazevic)			
10:50	00:20	CHENG, Rui	Research Progress of Ion Beam – Plasma Interactions at HIRFL – A Key Issue for HED @ HIAF
11:10	00:20	SHI, YuanFeng	Investigating the Electron Collisional Dynamics Through Non-Thermal Electron Distributions
11:30	00:20	LIU, Yun	Molecular Dynamics Investigation of the Stopping Power of Warm Dense Hydrogen for Electrons
11:50	00:20	NAZARY, Haress	Energy Loss Measurements with Laser Generated Ions
12:10	00:20	KOSTENKO, Oleg	Modeling of Generation of Characteristic X-Ray Radiation Under Vacuum Heating of Electrons of Nanocylinders
Session 15: LPA and WDM Diagnostics (Chair: Kurt Schoenberg)			
16:00	00:20	BELIKOV, Roman	Multi-Wavelength Pyrometer for Warm Dense Matter Temperature Measurements
16:20	00:20	VEYSMAN, Mikhail	A Model for Optical Diagnostics of the Spectrum of Electrons Accelerated in Laser Plasma
16:40	00:20	GERLACH, Sonja	Ionoacoustics for Particle Beam Monitoring: The I-BEAT Detector
17:00	00:20	DOYLE, Leonard	Monitoring Charge State Distributions of Residual Gas Ionization by High Intensity Laser Pulses
17:20		SCHOENBERG/BAGNOUD	**Conclusion and End of Workshop**

Implementation of an On-Shot Focal Spot Optimization Loop at PHELIX

Jonas Benjamin Ohland (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Udo Eisenbarth (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Bernhard Zielbauer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Yannik Zobus, Dustin Posor (TU Darmstadt), Johannes Hornung (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dirk Reemts (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

In modern laser systems, peak powers of up to 10 petawatts can be achieved. At the same time, the peak intensity in the focal plane can still be limited by wavefront (WF) aberrations. While Adaptive Optics (AO) [1,2] is often used to stabilize the WF and correct for aberrations before the compressor, doing so after pulse compression still poses a challenging problem: The large beam diameters and high peak intensities limit the possibilities to implement relay imaging and thus make the construction of on-shot WF sensors difficult.

Last year, we presented an alignment procedure for off-axis parabolic mirror (OAP) telescopes, which are a viable solution for this problem [3]. This technology enabled us to design an ultra-compact, post-compressor WF sensor at the Petawatt High-Energy Laser for heavy Ion eXperiments (PHELIX) at the GSI Helmholtzzentrum für Schwerionenforschung (GSI). This sensor is able to measure the WF over the full, 28 cm wide aperture of PHELIX within a footprint of only 2x1 meters and shall be used to run a post-compressor AO loop for focal spot optimization. Recently, the on-shot optimization and measurement capabilities of this system were demonstrated in a dedicated experimental campaign by observing the transmitted laser light through polystyrene foil targets of different thicknesses.

In this presentation, we describe the concept and implementation of the sensor. Furthermore, we give an overview of the calibration routine and an estimation of the on-shot intensity boost that can be achieved using the AO control loop. Finally, we present the results of the experimental campaign that clearly show the increased intensity and thus the potential performance gain of PHELIX.

Key Physical Processes During Laser Action in Condensed and Hollow Silica-Based Optical Fibers

Vladimir Efremov (JIHT RAS)

Systems transmitting laser radiation are developing quickly recent some ten years. For every tested system by us it was been detected its own critical laser energy density. Above this limiting value, the operability of the system as a whole is disrupted. Propagation velocities of critical laser energy density depends on laser parameters. In general, they all damage the carried material and move towards the energy source. Local disturbance of light conductivity leads to isochoric release of heat, its thermal decay with the generation of shock waves Experimental measurement were obtained for condensed [1-5] and hollow optical fibers [6,7].

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Influence of the Stretcher Beam Size on the Temporal Contrast of Short Laser Pulses in CPA Laser Systems

Simon Röder (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The study of a multitude of laser-plasma based applications, such as radiation pressure acceleration and surface high harmonics generation, requires a laser pulse with a clean temporal profile, in order to avoid pre-heating and pre-expanding the target. It is a common understanding that the various features in the temporal profile of short pulses amplified by CPA have different origins, which prevents addressing all these problems at once. Most modern PW-facilities have to resort to workarounds like plasma mirrors in order to push the overstepping of the ionization threshold close enough to the maximum intensity, to reach regimes where the mechanisms are viable. While plasma mirrors improve globally the temporal behavior of the pulse profile, they present many disadvantages. Since these mirrors are destroyed in each shot, this solution is costly and time consuming. In addition, the use of a double plasma mirror setup reduces the laser energy by nearly 50%. The reason why most facilities use them anyway is the lack for laser technological alternatives.
In this work, we address an aspect of the temporal contrast that has received little attention so far, namely the slow intensity rise happening on a picosecond time scale, from the ASE pedestal up to the last instants before the maximum of the pulse.
Due to large improvements in laser design and the incorporation of ultra-fast nonlinear effects such as uOPA, the temporal contrast has become less and less limited by pedestals on the ns-scale and prepulses over the past decades. Instead, it is now mainly limited by the rising edge in the ps-scale, due to semi-coherent scattering effects that are caused whenever a spectrally separated laser pulse is reflected from a surface.
The two situations in a CPA system where these conditions are met are in the grating-based stretcher

and compressor. We found a strong dependency between the rising edge and the laser beam size in these components. Here, we present an analytical description of how this dependency manifests itself in the temporal profile. Furthermore, we demonstrate a numerical and experimental verification of this theory. Doing so, we showcase how to exploit this dependency in order to reach a 5-ps contrast of up to nine orders of magnitude, which is well below the ionization threshold for most targets and intensities.

A Millijoule Ultrafast Optical Parametric Amplifier for the PHELIX and PENELOPE Frontends

Yannik Zobus

With the introduction of the technique of chirped pulse amplification (CPA) [1], the development of ultra-high intensity lasers around the world has been progressing rapidly and intensities up to the level of 10^{23} W/cm^2 have been achieved [2]. Although reaching these intensities is very interesting for laser-plasma experiments, it becomes significantly more crucial to be in control of the temporal contrast, since the ionization of targets may initiate at laser intensities as low as 10^{10} W/cm^2. Therefore, several pulse cleaning techniques such as cross-polarized wave generation (XPW) [3], second harmonic generation (SHG) [4] and ultrafast optical parametric amplification (uOPA) [5,6] have been established to enhance the temporal laser contrast. While the techniques of XPW and SHG are used to reduce already existing temporal disturbances like pre-pulses or amplified spontaneous emission (ASE), uOPA aims to amplify the still clean pulse without degrading the temporal laser contrast.
The latter has been used for many years to pre-amplify laser pulses up to several microjoules and has been proven to work robustly and solve the problem of ASE reliably. However, since pre-pulses are usually generated in high gain amplifiers, such as regenerative amplifiers, which are located further down in the amplification chain, they still impose a threat to high intensity experiments. Yet, a solution to this would be to enhance the output energy of the uOPA up to the millijoule-range and to replace these regenerative amplifiers. This would enhance the temporal laser contrast, while keeping the complexity of the laser system at the same level.

In this work, we present the status of our upgraded uOPA system, which consists of two amplification stages pumped by a frequency-doubled ytterbium based pump amplifier, aiming to reach an amplification above 1 mJ. In order to do this pump pulses with energies above 100 mJ prior to compression and SHG are created in a two-stage CPA system with a fiber pre-amplifier and a regenerative main amplifier. Due to a self-phase modulation seed-stage of the pre-amplifier, this pump laser accepts seeds in a large spectral range and the uOPA system is applicable to a wide range of systems around a wavelength of 1 µm.

We will report on details and performance of this laser frontend architecture developed to be used as a millijoule-level seed for both the neodymium-based PHELIX [7] laser and the ytterbium-based PENELOPE [8] laser at the Helmholtz-Zentrum Dresden - Rossendorf, Germany.

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Relativistic Interaction of Ultra-High Contrast Femtosecond Laser Pulses With Low-Z Core, High-Z Shell Composite Nanowire Arrays

Ehsan Eftekhari-Zadeh (Friedrich Schiller University Jena), M. Gyrdymov (Goethe-Universität Frankfurt am Main), Parysatis Tavana (Goethe University), Robert Lötzsch (Friedrich-Schiller-Universität Jena(FSU-IOQ)), Ingo Uschmann (Friedrich Schiller University Jena), T. Siefke (Fraunhofer Institute for Applied Optics and Precision Engineering IOF), U. Zeitner (Fraunhofer Institute for Applied Optics and Precision Engineering IOF), Olga Rosmej (GSI, Darmstadt), D. Kartashov (1Friedrich Schiller University Jena), Christian Spielmann (FSU Jena)

We report experimental results on the relativistic interaction of intense ultra-short laser pulses with arrays of composite nanowires using complex diagnostics, including X-ray and particle spectra. The low-Z (Silicon), $\geq$ 5 μm wire length, 150 nm diameter, 400 nm regular spacing core nanowires were etched into a 50 μm thick Si membrane and subsequently coated by a 25 nm thick layer of Titanium dioxide (high-Z cladding) using the atomic layer deposition (ALD) technique. The experiments were conducted at the multi-terawatt Ti:Sapphire laser system JETI 40, delivering 0.7 J, 30 fs laser pulses at 0.8 μm wavelength and 10 Hz repetition rate. To ensure high temporal contrast, the laser pulses were frequency-doubled with an efficiency $\approx$20% providing 40 fs pulses with a central wavelength of 400 nm and a temporal contrast $\leq 10^{-12}$. The second harmonic beam was focused by an Al off-axis parabolic mirror under 90º incidence angle onto the focal spot with a diameter of $\approx$2 μm on the target reaching intensities above $3\times10^{19}\ W/cm^2$ ($a_0\approx 2$).

Two crystal spectrometers with X-ray CCD cameras as detectors were used for high resolution measurements of X-ray line emission from high charge states of Si and Ti. A flat KAP crystal was used for measurements of X-ray spectra emitted from Si in the spectral range 1.7-2.5 keV (covering K-line emissions from neutral Si to Si^{13+}) and an imaging crystal spectrometer by using a toroidally bent GaAs crystal with 111 reflection and CCD detection. This provides a spectral resolution of 3500 and a spatial resolution of 5 micron for measurements of Ti lines in the energy range 4.5-4.95 keV (covering K-line emissions from neutral Ti to Ti^{21+}). The spectral analysis of K-shell X-ray emission lines revealed strong emission from Ti^{20+} (He-like) and weak emission from Ti^{21+} (H-like) ions, as well as strong emission from Si^{12+} (He-like) and Si^{13+} (H-like). Comparison to the reference flat targets (50 μm thick Ti foil and 50 μm thick Si substrate coated by 25 nm Ti layer) show an order of magnitude increase in the intensity of the line emission from He- and H-like ionic states of Ti achieved with nanowire arrays. Comparing the measured Ti X-ray emission with simulations using the collisional-radiative code FLYCHK predicts for the plasma an electron temperature of 2 keV and an electron density of 2×10^{23} g/cm^3. Moreover, 1D imaging of the X-ray emission from the Ti plasma shows that, in addition to the main source of the He-like emission localized at the target surface, a weak He-like emission with the spatial extension up to 1 mm from the target surface is detected from the nanowire array targets (but not from the reference flat targets!!!). Such spatially extended He-like emission was observed before in experiments with high energy nanosecond laser pulses irradiating flat targets. Here, we observe this phenomenon for femtosecond pulse duration. Considering extremely short (tenses of femtoseconds) radiative lifetime of the excited electronic states in He-like Ti^{20+} ions, this observation suggests an anomalously long lifetime of the relatively dense and hot plasma.

Finally, our particle diagnostic consists of electron and proton spectrometers based on permanent magnets with image plates as a detector, located at the front and at the back sides of the targets along the direction of the laser beam and in the backward direction. The measured spectra of protons ejected from the front side of the nanowire array targets show a 3× increase in the effective proton temperature as compared with protons generated from the reference target. More details and the analysis of electron spectra will be presented at the conference.

All-Optical Ultrafast Spin Rotation for Pre-Polarized Charged Particle Beams

Wenqing Wei (Xi'an Jiaotong University)

An all-optical ultrafast method of spin rotation has been investigated via the single-shot interaction of pre-polarized charged particle beam co-propagating with a temporally asymmetric laser pulse by using the semi-classical spin-resolved numerical simulations. We demonstrate that the spin-polarization direction of beam mainly depends on a tunable retard phase between the comparable time-integrated spin procession frequency and momentum angular frequency, which is determined by the elongated interaction cycles in the asymmetric field with reduced local instantaneous frequency, resulting in integrated nonzero magnetic field. Proton beam with transverse spin-polarization can be effectively rotated to longitudinal polarization (and vice verse) with average polarization degree above 95% and significantly accelerated up to hundreds of MeV in tens of femtoseconds by using a focused frequency-chirped Gaussian laser pulse. This spin-manipulation method is as well as feasible in utilizing a half-cycle THz pulse and applicable for other charged particles, such as electrons and tritium ions, requiring laser intensities proportional to the particle charge-mass ratio and g-factor, which could be achieved with currently available laser facilities. Energetic particle beams with any-desired direction of high spin-polarization produced by this rotation method have important applications in high-energy accelerators as injection sources and spin-dependent nuclear physics, etc.

Research Progress of Ion Beam – Plasma Interaction at HIRFL - A Key Issue for HED @ HIAF

RUI CHENG (INSTITUTE OF MODERN PHYSICS, CHINESE ACADEMY OF SCIENCES), Zhao Wang (IMP), Zexian Zhou (IMP), Yuyu Wang (IMP), Yu Lei (IMP), Yanhong Chen (IMP), Lulin Shi (IMP), Jie Yang (IMP)

HIAF, a new high intensity heavy ions accelerator, will be built in several years in Huizhou, China and the HEDP is one of the important research topics. Ions – plasma interaction, a key issue for intense heavy ion beam driven high energy density matter, has been studied based on HIRFL at Lanzhou. Energy loss and transportation of ions beam in plasma surrounding could be very different comparing that in cold matter, since the collisions between ions and free electrons domain, as well the plasma wake-field starts playing the roles.
In this workshop we will report our recent works on the low energy regime ions – plasma interaction based on HIRFL.

Investigating the Electron Collisional Dynamics Through Non-Thermal Electron Distributions

YuanFeng Shi (University of Oxford), Justin Wark (University of Oxford), Sam Vinko (University of Oxford), Shenyuan Ren (University of Oxford), Oliver Humphries (HZDR), Quincy van den Berg, Eric Galtier, Bob Nagler (SLAC), Hae Ja Lee (SLAC)

When intense x-rays, such as those produced by an x-ray FEL, interact with a solid target to produce a plasma [1,2], electrons are excited into the continuum via photo-excitation and Auger decay, providing a controlled source of electrons that are well-defined in energy, being a function of the atomic properties of the target and the energy of the FEL beam. Owing to the dense nature of the system, these electrons rapidly thermalise due to collisional effects [3,4], yet during the FEL pulse itself a non-thermal component of the electron distribution function will persist. In principle, information concerning the collisional dynamics and the evolution of the electron distribution function could be gleaned from a diagnosis of this non-thermal component, providing important insight into several aspects of the physics of dense plasmas. We present here an analysis of how such a measurement might be obtained via the use of a combination of x-ray Thomson scattering and emission spectroscopy. Initial results are compared with simulations from the CCFLY code, and appear promising for further studies.

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Molecular Dynamics Investigation of the Stopping Power of Warm Dense Hydrogen for Electrons

Yun Liu

A variety of theoretical models have been proposed to calculate the stopping power of charged particles in matter, which is a fundamental issue in many fields. However, the approximation adopted in these theories will be challenged under warm dense matter conditions. Molecular dynamics (MD) simulation is a good way to validate the effectiveness of these models. We investigate the stopping power of warm dense hydrogen for electrons with projectile energies ranging from 400–10000 eV by means of an electron force field (eFF) method, which can effectively avoid the Coulomb catastrophe in conventional MD calculations. It is found that the stopping power of warm dense hydrogen decreases with increasing temperature of the sample at those high projectile velocities. This phenomenon could be explained by the effect of electronic structure dominated by bound electrons, which is further explicated by a modified random phase approximation (RPA) model based on local density approximation proper to inhomogeneous media. Most of the models extensively accepted by the plasma community, e.g., Landau-Spitzer model, Brown-Preston-Singleton model and RPA model, cannot well address the effect caused by bound electrons so that their predictions of stopping power contradict our result. Therefore, the eFF simulations of this paper reveals the important role played by the bound electrons on stopping power in warm dense plasmas.

Energy Loss Measurements With Laser Generated Ions

Haress Nazary

A key process in inertial confinement fusion is the energy deposition of ions in dense plasma. It determines the alpha-particle heating which is expected to trigger the burn wave. Ion stopping in plasmas is studied mostly with high ion velocities where the theory is in agreement with the data. For low projectile velocities the existing theories show high discrepancies. Since conclusive data is missing in this regime we plan to conduct an experiment with higher temporal resolution than previous experiments. The high temporal resolution is important because the plasma parameters are changing on the ns timscale. Therefore, the temporal length of the plasma-probing ion bunches should be as short as possible to reduce the uncertainties caused by the averaging over the fast-changing plasma parameters.

To achieve this the Laser Ion Generation, Handling and Transport (LIGHT) beamline will be providing the ion beam. In the last few years, the LIGHT collaboration was able to generate intense 8 MeV proton bunches with a temporal width lower than 1 ns (FWHM). In order to get experimental data in the most important regime ($v_{\text{projectile}} \approx v^e_{\text{thermal}}$), ion bunches with lower energies (< 1 MeV/u) are necessary. In 2021 laser accelerated carbon ions were transported with two solenoids and compressed temporally with a radio frequency cavity. A pulse length of 1.2 ns (FWHM) at an energy of

0.6 MeV/u was achieved. The temporally compressed and spatialy focused ion beam will be used for energy loss measurements. The plasma will be generated by a nanosecond laser (nhelix) which is in the process of
upgrading.

In my talk I will present the planned experiment, its requirements and show its feasibility based on preperational beamtimes and predictive simulations.

Modeling of Generation of Characteristic X-Ray Radiation Under Vacuum Heating of Electrons of Nanocylinders

Oleg Kostenko (Joint Institute for High Temperatures of Russian Academy of Sciences (JIHT RAS))

A model is developed for the generation of hot electrons near the surfaces of ionized cylinders by a laser field of nonrelativistic intensity, which allows one to go beyond the electrostatic approximation and takes into account the absorption of the laser field energy by the generated electrons. A model of characteristic x-ray generation in a copper substrate, when the cylinders are located on the substrate obliquely and parallel to each other, and the laser field propagates perpendicularly to the substrate, is also considered [1]. It is revealed that the K_α radiation yield depends rather strongly on the angle of inclination of the cylinders. The optimal parameters, the cylinder radius multiplied by the laser wavenumber, the angle of inclination of the cylinders, and direction of the linearly polarized laser electric field, are determined at the normalized laser field amplitude a_L = 0.2. With these parameters, the yield of K_α radiation from a copper substrate covered with cylinders is 2.7 times higher than the maximum yield of K_α radiation from the substrate covered with ionized clusters under the same irradiation conditions and 4 times higher than the maximum yield of K_α radiation from a flat copper target irradiated by a p-polarized laser field of the same amplitude. An increase in the yield of K_α radiation from the substrate covered with nanocylinders as compared to the yield of K_α radiation from the substrate covered with ionized clusters is due to an increase in the number of accelerated electrons. An increase in the yield of K_α radiation from the substrate covered with nanocylinders, compared with the yield of K_α radiation from a flat target, is connected with both an increase in the number of accelerated electrons and a decrease in the absorption of K_α radiation in the substrate.

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Multi-Wavelength Pyrometer for Warm Dense Matter Temperature Measurements

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The pyrometrical determination of surface temperatures by an analysis of thermally emitted light is often the only available method for Warm Dense Matter temperature measurements. These measurements could be fulfilled, for example, during heavy ions heating experiments at FAIR. Here, the design of a flexible and accurate pyrometer for these applications is presented.

The pyrometrical technique is based on measurements of wavelength-dependent thermal radiation or spectral radiance, and its "comparison" to that of blackbody (Planck) radiation or its Wien's approximation. The main uncertainty in traditional pyrometry is the surface emissivity ε, which is generally unknown and hard to measure. A common approach to deal with this problem is to measure the thermal emission at multiple wavelengths – an approach called multi-wavelength pyrometry [1]. The emissivity in that case is approximated by some function of the wavelength.

In practice, the grey body approximation ε(λ) = const is commonly used, but it is accurate only for certain materials in a narrow temperature and wavelength range. As a more advanced technique a polynomial dependence of ε(λ) on λ is often assumed. The temperature is then determined from a fit, in which the polynomial coefficients and the temperature are variables. The most popular multi-wavelength pyrometry emissivity models are the linear model, the polynomial model, and the exponential raised to a polynomial emissivity model [2, 3].

Our new pyrometer uses 8 wavelengths from 600 to 1500 nm and different types of detectors, such as photodiodes and Multi Pixel Photon Counters (MPPC) for low levels of light, which is a a new technical development in pyrometry. This allows one to measure the temperature in a broad temperature range up to few thousand Kelvins with high temporal resolution up to nanoseconds.

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A Model for Optical Diagnostics of the Spectrum of Electrons Accelerated in Laser Plasma

Mikhail Veysman (JIHT RAS), Nikolay Andreev (JIHT RAS), Leonid Pugachev (Joint Institute for Temperatures of the Russian Academy of Sciences)

The possibility of diagnostic of the energy spectrum of an electron beam accelerated in an ion channel formed in a near-critical density plasma under the action of a powerful laser pulse using the spectrum of their synchrotron radiation is demonstrated. It is shown that the temperature T_h of hot (super-ponderomotive) electrons and the maximum energy E_{max} of the electron beam can be determined from the high-frequency branch of the synchrotron radiation spectrum. The absolute value of the maximum of the synchrotron radiation spectrum $N_{0.1\%BW}(\omega)$ can be used to estimate the total number of electrons accelerated to energies up to E_{max} in the ion channel.

In addition, the temperature T_p of "thermal" (ponderomotive) electrons can be estimated, as well as the fraction N_p/N_h of these electrons relatively to the number of hot superponderomotive electrons. For this the low-frequency branch of the synchrotron radiation spectrum of an electron beam can be used. The use of both branches of the spectrum of synchrotron radiation: high-frequency and low-frequency ones, is useful for refining the parameters of the spectrum of both ”thermal” and ”suprathermal” electrons.

Ionoacoustics for Particle Beam Monitoring: The I-Beat Detector

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Ionoacoustics is a novel method that employs the acoustic wave emitted by pulsed ion beams stopping in water. To determine ion bunch properties on a single bunch basis, we have developed the I-BEAT (Ion-Bunch Energy Acoustic Tracing) detector based on the ionoacoustic principle. The I-BEAT set-up consists of a water phantom equipped with up to four commercial ultrasound transducers. Being electromagnetic pulse (EMP) resistant, this method is especially suited for laser-accelerated ions. Additionally, the detector enables online data evaluation while being compact and cost-effective.
To be optimally adapted to different application requirements, several detector set-ups have been tested. To measure the bunch properties of a laser-ion source directly behind the target, I-HOG was developed with an extra-large entrance window accounting for the highly divergent bunches. Promising proof of principle experiments were conducted at the PHELIX laser (GSI, Darmstadt). Furthermore, a smaller version of the detector dedicated to three-dimensional dose reconstruction of focused and energy selected laser-accelerated ions was engineered, the so-called I-BEAT 3D. It was successfully tested at the DRACO laser system (HZDR, Dresden). During this campaign, the ion bunch position could be resolved with sub-millimetre sensitivity. Additionally, the suitability for absolute dosimetry was shown using an ionization chamber as a reference. Besides the development of the detector set-up, we are working on suitable online reconstruction methods. As the evaluation speed is especially important for high repetition rate systems, we particularly focus on fast reconstruction algorithms based on analytical ultrasound models.

Monitoring Charge State Distributions of Residual Gas Ionization by High Intensity Laser Pulses

Leonard Doyle (Ludwig-Maximilians-Universität München), Michael Bachhammer

(Ludwig-Maximilians-Universität München)

We investigated a simple setup to detect charged ions that are generated by intense laser pulses close to the focal region. A noble gas (e.g. Argon) is introduced at low background pressure into the experimental chamber. The atoms are partially ionized by the laser pulse and extracted by a homogeneous DC electric field that we adjusted between 2 and 4 kV/cm. After a drift length of 25 cm they are registered by a silicon photomultiplier (SiPM) diode, which provides a temporal resolution of 1 ns and is in principle capable of single particle detection.
We will present first results of experimental campaigns conducted in 2021 at the laser-ion acceleration chamber at the Centre for Advanced Laser Applications in Garching with the Advanced Titanium Sapphire Laser ATLAS-3000. The experiments were performed at laser intensities beyond 10^{19}W/cm² and we observed maximum charge states of Ar^{16+}. The time-of-flight signals contain rich information on charge state distributions that are partially correlated to peak intensity. In particular, we observed that the signal shape of the highest charge state in Argon strongly depends on the spectral phase, which we manipulated via a Dazzler integrated in the ATLAS front end.
Although not calibrated yet, the simple setup might become interesting in the framework of residual gas analysis within the focal volume or as a performance monitor for peak intensity at full laser power.
This work was supported by the German Research Foundation (DFG) within the projects FOR2783/1 and GRK2274 and the BMBF under project 05P21WMFA1.

Poster session 1 (Wednesday, 15:00-16:30)

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W4	KHURCHIEV, Aiush	Calibration of Image Plates for Pulsed Plasma Diagnostic
W5	GAVRILIN, Roman	Stopping Power Measurement for 100 KEV/U FE Ions in Hydrogen Plasma
W6	CHINTALWAD, Sachin	Photon Emission Enhancement Studies from the Interaction of Ultra-Intense Laser Pulse with Shaped Targets
W7	KUMAR, Punit	Filamentation In Spin Polarized Magnetized Quantum Plasma
W8	KRASIK, Yakov	Compact High-Current Pulse Generator for Laboratory Studies of High Energy Density Matter
W9	HUMPHRIES, Oliver	Characterizing the Ionization Potential Depression in Dense Plasmas with High-Precision Spectrally Resolved X-ray Scattering
W10	CHEN, Lei	Effect of Viscosity on Stopping Power for a Charged Particle Moving Above Two-Dimensional Electron Gas
W11	PAPP, Istvan	Particle Simulations for Nanoplasmonic Laser Induced Fusion Experiments
W12	POSOR, Dustin Jonas	Wavefront Measurement Using Beams with Orbital Angular Momentum: Preliminary Investigations
W13	TAVANA, Parysatis	Diagnostic of Laser-Accelerated MeV Proton Beams from Near Critical Density Foam Targets Using Nuclear Activation Technique and Radiochromic Film Imaging Spectroscopy
W14	MARTYNENKO, Artem	Optimization of a Laser-Plasma-Based Hard X-Ray Source for Absorption Spectroscopy Diagnostic of Warm Dense Matter
W15	LIPP, Vladimir	Applying Density Functional Tight Binding Approach to Study X-Ray-Induced Phase Transitions in Solids
W16	KANTSYREV, Alexey	High Energy Density Science at ITEP

Research Progress of Ultrafast Photoelectric Diagnostics in XIOPM CAS and Its Application Prospect in HED Physics

Yang Yang (Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710049,)

The gated X-ray framing cameras with picosecond temporal resolution and micron spatial resolution are indispensable two-dimensional diagnostic instruments for inertial confinement fusion (ICF) and high-energy density (HED) physics research. The ultrafast photoelectric diagnostics group in XIOPM CAS has been committed to developing cutting edge framing technology for decades to achieve higher detection efficiency, shorter exposure time and to detect photons with higher energies. A hermetically sealed gated MCP imager with a CsI photocathode is developed as a more effective and stable alternative to the traditional open-structured imager, and experiments show that its detection efficiency is 13 times higher than that of traditional imager. The pulse dilation technology has been adopted to develop time-domain modulation framing camera with a temporal resolution of 5 ps. To detect time resolved Compton radiographic images, a dual MCP framing camera is developed, which is sensitive to photons with energies higher than 50 keV. These techniques and cameras are applicable to the HED community for elucidating the properties and structure of HED matter. One possible scheme is to use the framing camera as the detector of X-ray backlight imaging to obtain multiple time resolved images with high signal-to-noise ratio in a single shot. This technology will make it possible to explore the hydrodynamics of HED matter.

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

Bubo Ma, Yongtao Zhao (XJTU & IMP), Jieru Ren (Xi'an Jiaotong Unversity)

White dwarfs play important roles in stellar evolution and help us gauge the age of our galaxy. The white dwarf H1504+65, the hottest known post-asymptotic giant branch star, is peculiar due to its C- and O-rich but He- and H-deficient atmosphere whose composition cannot be well predicted by current stellar evolution models. The analysis of the elemental abundance and the benchmark of stellar atmospheric models depends heavily on spectral data under cosmic conditions, which are currently extremely scarce.

We created a well-defined, uniform, relatively large-scale $\sim$millimeter plasma sample in the laboratory with a temperature and a C/O ratio similar to those of H1504+65's atmosphere. The emission spectra with high precision in the range of 10–80 nm were obtained and identified according to databases such as NIST and Kelly. A detailed comparison between our emission lines and the Chandra-observed white dwarf H1504+65 atmosphere's absorption lines was performed. The stongly isolated O VI lines in the range of 10–13 nm are observed in both cases. We observed a wealth of O V lines in the range of 13–14 nm that cannot be well identified or predicted by models due to the weak flux and also probably due to the blending effect of Fe group elements in the Chandra spectrum. Long-wavelength lines ranging from 14 to 80 nm, which are not observed in the Chandra spectrum because of the high interstellar neutral hydrogen column density, show abundant O IV-V, C IV lines, and strong O VI lines. Moreover, the intensities of the lines at 62.973 and 17.216 nm are analyzed to characterize the plasma temperature.

Warm Dense Matter Analysis Through Hydrodynamics and Stopping Power

Francisco Chacon Rubio (UCLM), Manuel Domingo Barriga-Carrasco (UCLM)

Dense plasmas in the Warm Dense Matter (WDM) regime are of great interest as a probe of stopping power theories. WDM is extremely difficult to treat theoretically due to the simultaneous appearance of quantum degeneracy, Coulomb correlations, and thermal effects. Also, the coexistence of plasma and condensed phases force stopping power theories to consider both, free and bound electrons.
Many stopping power models in plasma use density, temperature, and ionization state as input parameters. Therefore, an accurate description of the plasma is necessary to perform these calculations correctly. As these values are not always available from the real plasma, hydrodynamic simulation become a handy solution to obtain key plasma parameters. In this study, we have performed hydrodynamic calculations based on a real experiment [1] with the help of a hydrodynamic codes. The basic physics processes included in the code employed are hydrodynamic equations, thermal flux, electron-ion relaxation, electron collisions and laser energy deposition. We present the profiles of density, temperature and ionization obtained and discuss their validity as well as the shortcomings of the simulation.
Finally, stopping power calculations with our SLPA model [2] and other models, which explicitly account for bound electrons, are compared with the experimental measured stopping power. Our SLPA model is based on a dielectric function for quantum plasmas [3] of free electrons and includes explicitly the binding energies of bound electrons through the Levine-Louie dielectric function [4]. With this we expect to test the validity of the stopping power models considered in general, and of the SLPA model in particular, for stopping power predictions in WDM. Furthermore, we seek to test the performance of the hydrodynamic calculations, aiming to support further proposed experiments providing useful data about the plasma evolution.

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Calibration of Image Plates for Pulsed Plasma Diagnostic

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Several types of detectors exist in order to diagnose high-energy ions and electrons of pulse plasma: CR-39, radiochromic films (RCF), scintillators and image plates (IP). Although an IPs is passive detectors and cannot be used in high repetition rate experiments, IPs has several advantages over other

particle detectors: persistency to electromagnetic pulse, high dynamic range (up to 10^5), high spatial resolution (usually 10 – 50 µm). In addition, IP can be erased with white light, allowing for reuse. The most widely used IPs in plasma diagnostics are BAS (Biological Analysis System) image plates: BAS-MS, BAS-TR and BAS-SR, the sensitive layer of which is the $BaFBr_{0.85}I_{0.15} : Eu$ phosphor layer. When the detector is exposed to radiation, electrons of Eu^{2+} in the phosphor layer are ionized and trapped in FBr or FI sites, forming metastable states. During scanning, the phosphor layer is irradiated with 2 eV photons, electrons in metastable states are re-excited and recombine with Eu^{3+} and emit photons with energy of 3 eV (photostimulated radiation, PSL).
The signal with IP (PSL) obtained after scanning is proportional to the absorbed energy in the luminescent layer of the detector. However, there is no theoretical expression for the relationship between the PSL and the absorbed energy, which leads to the need for calibration the system «detector-scanner». In addition, some of the electrons in the metastable states recombine spontaneously, which leads to a decrease in the signal from the detector (fading effect). In this work, the BAS-MS and BAS-TR image plates were calibrated for electrons and alpha particles using the medical scanner VistaScan Mini from Durr Dental.

Stopping Power Measurement for 100 KeV/u Fe Ions in Hydrogen Plasma

Roman Gavrilin (Institute of Theoretical and Experimental physics of NRC Kurchatov Institute), Alexander Golubev (ITEP), Alexey Kantsyrev (Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Center «Kurchatov Institute»), Aiush Khurchiev (NRC "Kurchatov Institute" - ITEP), Dmitry Kolesnikov (Institute for Theoretical and Experimental Physics of NRC «Kurchatov Institute», Moscow, Russia), Vasily Volkov (NRC 'Kurchatov Institute' - ITEP), Alexander drozdovsky (NRC «Kurchatov Institute» - Institute of theoretical and experimental physics, Moscow, Russia), Andrey Kuznetsov (National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)), Sergey Visotsky (NRC «Kurchatov Institute» - ITEP), Igor Roudskoy (ITEP, Moscow), Sergey Savin (NRC «Kurchatov Institute» - ITEP)

The study of energy loss processes of heavy charged particles in plasma refers to the fundamental problems of plasma physics and physics of high energy density in matter. Investigation of heavy ions with energies in the range 40 – 500 keV/u interacting with strongly ionized plasma is of great importance because of the lack of experimental data [1,2]. Results of a stopping experiment with Fe^{+2} ions of 100 keV/u in hydrogen plasma are presented. The plasma parameters of the high-current gas-discharge target [3] were measured by the two-wave laser interferometry method [4]. The linear electron density remains in the range from $2.410^{17} cm^{-2} to 1.210^{18} cm^{-2}$ while the initial hydrogen pressure changes from 1 to 4.5 torr and the capacitor voltage – from 1.5 to 5 kV. The maximum observed plasma ionization degree (0.82 ± 0.08) was achieved at the initial hydrogen pressure of 1 torr and the voltage of 5 kV. The measurement error was less than 10%. The temperature of the hydrogen plasma was in the range 1.01 - 1.06 eV and varied slightly depending on the initial discharge parameter. The energy losses of 100 keV/u Fe^{+2} ions in the hydrogen plasma were measured at the "TIPr" linear accelerator in the ITEP [5]. For Fe^{+2} ions with an initial energy of 5.6 MeV the total energy losses in the plasma were in the range from 0.4 up to 1.15 MeV. According to the experimental data obtained, the stopping power of free electrons was 860 ± 130 MeV/(mg/cm^2) for the ions under consideration. This result was compared with previously performed theoretical calculations and the numerical simulation using the SRIM code. It has been shown that the stopping power of ionized

hydrogen exceeds the stopping power of cold gas more than 15 times
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Photon Emission Enhancement Studies From the Interaction of Ultra-Intense Laser Pulse With Shaped Targets

Bhuvanesh Ramakrishna (IIT Hyderabad), Sachin Chintalwad (IIT Hyderabad)

We study the photon emission by Bremsstrahlung and Non-linear Compton Scattering (NCS)from interaction of ultra-intense laser pulses with cone target and flat foil using particle-in-cell (PIC) simulations. The simulations are performed for laser pulse interacting with Al and Au targets. The strength of the two mechanisms of photon emission from Bremsstrahlung and nonlinear Compton cattering are compared. When an ultra-intense (I > $10^{22} W cm^{-2}$) laser interacts with a cone and a foil target, photon emission by Bremsstrahlung is found to be comparable to that from nonlinear Compton scattering. The obtained electron energy as well
as the energy and number of photons emitted were found to be higher in case of cone shaped target compared to that of a foil target. The enhanced photon emission from cone shaped target is attributed to the guiding or collimation of hot electrons towards the cone tip from the selfgenerated magnetic field and electrostatic field along the cone surface which pushes the hot electrons towards the tip.

Filamentation in Spin Polarized Magnetized Quantum Plasma

Punit Kumar (University of Lucknow, India)

The plasma, where the inter-particle distance approaches the de-Broglie wavelength, or the temperature goes below the Fermi temperature, plasma particles obey Fermi-Dirac statistics and degeneracy starts playing a significant role. In such cases, study of quantum effects become important due to the important applications of quantum plasma ranging from plasmonics, astrophysics, ultracold plasmas, inertial confinement fusion (ICF), future generation compression based plasma experiment, quantum well to quantum x-ray free electron laser and laser-solid density plasma experiments. There is a great motivation to investigate collective phenomenon in quantum plasma where Bohm potential, Fermi pressure and electron spin as well as certain quantum electro-dynamical effects have been accounted for. Filamentation in quantum plasma have been studied by various authors but all the previous studies considered electrons as a single fluid of macroscopically averaged spin-1/2 plasma. These papers did not show a full picture as they didn’t took spin-up and spin-down interaction force into account. Very recently, a modified separate spin evolution (SSE) treatment of electrons in accordance with Pauli equation has been developed. In the present paper, using the modified model the filamentation of a short laser pulse in a magnetized quantum plasma is presented. Spin-up and spin-down electrons have been taken to be separate species of particles and spin-spin interaction picture has been developed. The effects of quantum Bohm potential, electron Fermi pressure and spin have also been taken into account. The direction of the external field has been taken to be along the direction of electron beam propagation in the first case and oblique in the second case. The dispersion for both the cases have been obtained and growth rate evaluated. The results of both the cases have been compared and analyzed.

Compact High-Current Pulse Generator for Laboratory Studies of High Energy Density Matter

Yakov Krasik, Sergey Efimov (Physics Department, Technion), Daniel Maler (Physics Department, Technion), Svetlana Gleizer (Physics department, technion), Evgeni Flyat (Physics Department, Technion)

We present the design and parameters of a compact and mobile high-current pulse generator which can be applied in the study of warm dense matter in university laboratories. The generator dimensions are 550 mm $\times$570 mm $\times$590 mm, weight $\sim$70 kg and it consists of four “bricks” connected in parallel. Each brick, made up of 2×40 nF, 100 kV low-inductance capacitors connected in parallel, has its own multi-gap and multichannel ball gas spark switch, triggered via a capacitively coupled triggering by a positive polarity pulse of $\sim$80 kV amplitude and $\sim$15 ns rise time. At a charging voltage of $\sim$70 kV, the generator produces a $\sim$155 kA current pulse with a rise time of $\sim$220 ns on a $\sim$15 nH inductive short-circuit load and a $\sim$90 kA amplitude current pulse in the underwater electrical explosion of a copper wire.

Characterizing the Ionization Potential Depression in Dense Plasmas With High-Precision Spectrally Resolved X-Ray Scattering

Oliver Humphries (Helmholtz Zentrum Dresden Rossendorf), Julian Lütgert (HZDR), Katja Voigt (HZDR), Michael Stevenson (University of Rostock), Dominik Kraus (University of Rostock, HZDR)

Details of a recent experiment at the European XFEL will be presented, studying the ultrafast creation of dense plasmas by isochoric heating, and characterizing their properties. The high-precision X-ray scattering diagnostic used is particularly well-suited to probe the ionization potential depression as well as ionization and temperature. This approach has a high potential to resolve existing discrepancies on ionization potential depression models that are important for modelling celestial bodies like giant planets, Brown Dwarfs and stars as well as for several technological applications like intense laser matter interaction and radiation damage research.

Effect of Viscosity on Stopping Power for a Charged Particle Moving Above Two-Dimensional Electron Gas

Lei Chen (Huazhong University of Science and Technology)

In two-dimensional (2D) electron systems, the viscous flow is dominant when electron-electron collisions occur more frequently than the impurity or phonon scattering. In this work, a quantum hydrodynamic model, considering viscosity, is proposed to investigate the interaction of a charged particle moving above the two-dimensional viscous electron gas. The stopping power, perturbed electron gas density, and the spatial distribution of the velocity vector field have been theoretically analyzed and numerically calculated. The calculation results show that viscosity affects the spatial distribution and amplitude of the velocity field. The stopping power, which is an essential quantity for describing the interactions of ions with the 2D electron gas, is calculated, indicating that the incident particle will suffer less energy loss due to the weakening of the dynamic electron polarization and induced electric field in 2D electron gas with the viscosity. The values of the stopping power may be more accurate after considering the effect of viscosity. Our results may open up new possibilities to control the interaction of ions with 2D electron gas in the surface of metal or semiconductor heterostructure by variation of the viscosity.

Particle Simulations for Nanoplasmonic Laser Induced Fusion Experiments

Istvan Papp (Wigner Research Centre for Physics)

Nanoplasmonic Laser Induced Fusion Experiments were proposed recently, as an improvement in achieving laser driven fusion, combining new discoveries in heavy-ion collisions and optics[1]. The existence of detonations with time-like normal on space-time hyper-surfaces and absorption adjustment with embedded nanoantennas allows the possibility of heating the target inside opposing laser beam setup[2]. For tracking the time evolution of non-equilibrium plasma interacting with strong laser fields, kinetic modeling is required. However, for describing the absorption effects of nanoparticles different approaches are necessary[3]. Here we present a particle-in-cell model of implanted nanoantenna, investigating its absorption properties and stability when irradiated with intense laser beams.

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Wavefront Measurement Using Beams With Orbital Angular Momentum: Preliminary Investigations

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Many laser-plasma experiments such as TNSA or laser-wakefield acceleration rely on a well-defined intensity distribution in the focal plane. This property is directly linked to the wavefront (WF) of the laser beam in the nearfield, which is why WF measurement and control is crucial for the operation of such a system. Traditionally, WF measurement is done using nearfield sensors such as Shack-Hartmann sensors or Quadri-Wave Lateral Shearing Interferometry [1]. These approaches are, however, biased by aberrations introduced in their separated beam path and also insensitive to the aberrations of the beam path after the sampling position. In order to provide absolute measurement of the aberrations of the system, one has to do measurements in the focal plane. Phase retrieval [2] does offer such a solution at the cost of complicated data acquisition and evaluation, which renders this method rather impractical.
In this work, we investigated an alternative approach to WF measurement in the focal plane. Adding an orbital angular momentum to the beam under investigation yields a ring-shaped intensity distribution in the focal plane, which changes its shape distinctly under the introduction of aberrations [3]. After analysis of this intensity distribution, an iterative algorithm is being used to determine the strength of aberrations that were present in the original beam.
In this presentation, we explain the functional principle of this method and present results of simulations that we conducted in order to understand the limits of this approach. We have shown that small amounts of coma, astigmatism and trefoil in the Zernike sense are in principle detectable with an exceptionally high accuracy.

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Diagnostic of Laser-Accelerated MeV Proton Beams From Near Critical Density Foam Targets Using Nuclear Activation Technique and Radiochromic Film Imaging Spectroscopy

Mikhail Gyrdymov, Parysatis Mahmoodi Tavana (Goethe-Universität Frankfurt(UFfm)), Jakub Cikhardt (Czech Technical University of Prague (CTU)(CTU)), Marc Günther (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Sero Jakob Zähter (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Nikolai Bukharskii (National Research Nuclear University MEPhI), Olga Rosmej (GSI, Darmstadt), Joachim Jacoby

To enhance the proton acceleration from interaction of high intensity short-pulse laser with plasma, we have performed an experiment using near-critical density (NCD) foam targets stacked with metallic foil.

Two different methods, namely Nuclear Activation Technique and Radiochromic Film Imaging Spectroscopy were combined to characterize the proton beam. In the former, a multilayer detector of thin metallic foils with different energy thresholds for (p,xn)- reaction allows for reconstruction of proton spectral distribution over a wide range of proton energies.
It was experimentally verified that for the same laser intensity, the application of foam targets increases the number and cut-off energy of laser accelerated protons in comparison of thin metallic targets. In addition, backward proton acceleration in NCD foams with a cut off energy of 15 MeV was demonstrated.

Optimization of a Laser-Plasma-Based Hard X-Ray Source for Absorption Spectroscopy Diagnostic of Warm Dense Matter

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X-ray absorption spectroscopy (XAS) [C. Bressler and M. Chergui. Chemical Reviews, 4 (104), 1781, 2004] diagnostic has been proved to be an effective tool for warm dense matter (WDM) experimental studies. However, XAS requires a short-lived X-ray source (XRS) of sufficiently high emissivity and absence of intense characteristic lines in a spectral range of interest. In our resent study [A.S. Martynenko, et. al. Matter and Radiation at Extremes, 1 (6), 014405, 2021], we discussed choosing its optimum material and thickness to get a bright source in the wavelength range of 2-6 Å (2-6 keV) considering relatively low-Z elements. We demonstrated that the so-called photorecombination region of X-ray characteristic spectral emission is best suited for XAR using a laser-generated X-ray source, due to its featureless spectra of high intensity. Performed experiments showed that the highest emissivity of solid aluminium and silicon foil targets irradiated with a 1 ps high-contrast sub-kJ laser pulse of Vulcan PW laser facility is achieved when the target thickness is close to 10 µm. An outer plastic layer increases the emissivity even further [A.S. Martynenko, et. al. Phys. Rev. E 101(4), 043208, 2020].

Applying Density Functional Tight Binding Approach to Study X-Ray-Induced Phase Transitions in Solids

Vladimir Lipp (Institute of Nuclear Physics, Polish Academy of Sciences), Beata Ziaja (Electron Laser Science CFEL, DESY)

Computer simulation of X-ray-irradiated evolution of solids is essential for material processing applications and understanding extreme states of matter, such as warm-dense matter. Here, we present a dedicated simulation tool developed to simulate X-ray- and XUV-induced phase transitions in a broad range of solid materials. This is possible due to the modular structure of the tool and utilization of the well-known density functional tight binding code, DFTB+, to follow band structure evolution of the irradiated targets. The present computational scheme allows to simulate NVE thermodynamic ensemble for both atomic and electronic subsystems, which should make it also relevant to studies of laser-irradiated solids. The outstanding performance of the implementation is demonstrated with a study of the XUV induced graphitization in diamond.

High Energy Density Science at ITEP

Alexey Kantsyrev (Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Center «Kurchatov Institute»)

The Laboratory of High Energy Density in Matter Physics at NRC "Kurchatov Institute" - ITEP performs the experimental and theoretical study of physical processes of the extreme state of matter at ultrahigh pressures and temperatures. Most of the laboratory activity is aimed to development of diagnostic methods of matter under pulse action of powerful lasers, Z-pinches or intense heavy ion beams. The laboratory performs research in the field of plasma physics and the development of methods for plasma diagnostics. The recent activity of the HEDMP laboratory is aimed to:

• Development of novel diagnostic method – high-energy proton microscopy in frame of HED@FAIR collaboration of FAIR project. The participation in development and commissioning of new PRIOR-II proton microscope at GSI in progress.

• The full-scale Monte-Carlo numerical simulation of X-ray spectroscopy and spectrum reconstruction of pulsed plasma

• Development of charge particle diagnostics of pulsed plasma

• Research in the field of plasma physics at experiments of stopping power measurement for heavy ions in hydrogen discharge plasma.

Poster session 2 (Thursday, 15:00-16:30)

T1	GONZÁLEZ-GALLEGO SÁNCHEZ-CAMACHO, Luis	Experimental and Simulated Energy Loss in Magnetized Plasmas
T2	CHEN, Benzheng	Research on the Energy Loss Increase of Intense Proton Beams in Plasma
T3	REN, Jieru /MA, Bubo	Charge State Evolution of Laser-Accelerated Carbon Ions in Dense Ionized Matter
T4	JATAV, Bheem Singh	Kinetic Alfven Wave to Study Solar Coronal Heating
T5	QU, Chongbing	Chemical Properties of Mixtures at WDM Conditions Characterized by Precise Spectroscopy Methods
T6	SKOBLIAKOV, Aleksei	Numerical Simulation of Experiments for X-Ray Diagnostics of Pulsed Plasma
T7	BARABANOV, Mikhail	Probing of Exotic States in Hadron and Heavy Ion Collisions
T8	LEVASHOV, Pavel	Wide-Range Models of Transport and Optical Properties for Subpicosecond Laser-Metal Interactions: Current Status and Problems
T9	RODRIGUES, Gerard	Stripping of Heavy Ion Beams Using Laser Ablated and Pinch Plasmas
T10	KRASIK, Yakov	The Non-Linear Complete Absorption Phenomenon for High-Power Microwave in a Plasma Filled Waveguide
T11	RANJAN, Divyanshu	Characterising Insulator-Metal Transition of Hydrogen with Spectrally Resolved X-Ray Scattering
T12	ZHANG, Jia	Energy Relaxation and Electron Phonon Coupling in Laser-Excited Metals
T13	CIKHARDT, Jakub	Experimental Investigation of the Sub-Picosecond Laser Interaction with Low Density Foams on the PHELIX Laser System
T14	GYRDYMOV, Mikhail	Generation of High Energy Electrons and Protons in Interaction of Relativistic Laser Pulse with Foams of Sub-mm Thickness
T15	EHRET, Michael	EMP Measurements at VEGA
T16	KAMBOJ, Oriza	Stimulated Raman Scattering Coupled with Decay Instability in a Magnetized Plasma with Hot Drifting Electrons

Experimental and Simulated Energy Loss in Magnetized Plasmas

Luis González-Gallego Sánchez-Camacho (ETSII Ciudad Real, University of Castilla-La Mancha), Manuel D. Barriga-Carrasco (ETSII Ciudad Real, University of Castilla-La Mancha)

The energy deposition of the ion beams used in Inertial Confinement Fusion (ICF) is due to the stopping power of the plasma, and can be estimated, for instance, by means of the dielectric formalism and the dielectric function [1].

However, it is also important to be concerned about the influence of external magnetic fields that can modify the trajectory or energy of the projectile particles. It is not only important for ICF method, but also for magnetic confinement, astrophysics, ultracold plasmas studies, etc. [2-6] There are some theoretical models regarding magnetized targets for both the dielectric formalism [6-8] and binary collision [5]. Although there are models developed, there are not many that approach these topic and conditions.

In this work, we will introduce magnetic forces inside our simulation codes, focusing first in the totally ionized case, to easily observe the influence of a magnetic field in the energy loss of the projectiles. This new method will be benchmarked reproducing some of the cited models.

Recently, some experiments related to laser or ion interaction with magnetized plasmas have been performed in facilities like ELFIE, TITAN, or PEARL. For instance, in reference [9] is shown an experiment about particles accelerated by TNSA ion beams, generated by short-pulse lasers, that were shot against a neon gas jet or plasma in a 20 T magnetic field. If possible, our method will be used to obtain the same stopping power results as this experiment or similar ones.

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Research on the Energy Loss Increase of Intense Proton Beams in Plasma

Benzheng Chen (MOE Key Laboratory for Nonequilibrium Synthesis and Modulation of Condensed

Matter, School of Physics, Xi'an Jiaotong University, Xi'an 710049, China)

Here we report the energy loss enhancement of intense proton beams in plasma from aspects of theory, experiment and numerical simulation. Beam-density-effect theory proposed by McCorkle indicates that the stopping power is proportional to a well-defined number of beam particles that interact coherently. Besides, Deutsch refers to this phenomenon as correlation effects related to the vicinity of the fragment ions, which can enhance the energy loss compared with individual ions. We also reveal the stopping enhancement of intense proton beam experimentally, which can reach one order of magnitude compared with individual ion stopping models. Particle-in-cell (PIC) simulations are carried out to explain this energy loss increase as well. A strong resistive electric field attributable to the neutralization current and collective effect is the main reason.

Charge State Evolution of Laser-Accelerated Carbon Ions in Dense Ionized Matter

Jieru Ren *(Xi'an Jiaotong Unversity)*

The charge state evolution of heavy ion in plasma is of fundamental importance for alpha particle self-heating, ion driven HEDP, astro-observation explanation, and laser acceleration technology. The charge transfer process of heavy ion in matter attracted a lot attention these years. Various theories and semiempirical formula are developed, and some database and program are built. However, due to the complicated many-body property, the charge transfer of charged particles in plasma are far to be fully understood, and there are only few experimental data that support these models, especially in dense matter, the density effect might play important roles.
We experimentally measured the charge state distribution of laser-accelerated carbon ions passing through the dense ionized matter with XGIII laser facility. The dense ionized target with T 17 eV and ne 4*10^{20} cm^{-3}is produced by irradiating a Tri-Cellulose Acetate (TCA) foam sample with soft X-rays from a ns-laser-heated hohlraum. In this way, the ionized matter can be considered to be quasi static in time scale of 10 ns. The state of ionized matter is spectroscopically diagnosed.
The average charge state of carbon ions passing through the plasmas are calculated by using semi-empirical formula as well as by solving the rate equations. The rate coefficient of electron capture and loss for 0.5 MeV/u carbon in C-H-O plasmas. Through careful comparison between the experimental data and theoretical calculations, the target density was demonstrated to play important roles.

Kinetic Alfven Wave to Study Solar Coronal Heating

Bheem Singh Jatav *(Department of physics, Sikkim University, Gangtok, Sikkim)*

Kinetic Alfven waves are low frequency electromagnetic waves. I study the Kinetic Alfven Wave fluctuations for the solar coronal heating, when the background plasma density is modified by parallel ponderomotive force and Joule heating. The Kinetic Alfven wave plays a prominent role for solar coronal hearing and particle acceleration in space plasma. Numerical method has been used to analyse the evolution of KAW in solar corona [1]. The kinetic scale density fluctuation spectrum follows Kolmogorov scaling in inertial range [2]. Steepened spectrum has been achieved in the dispersive range, which is continues in the dissipation range. Our obtained results reveal that the kinetic scale density fluctuations plays an important results for transferring the energy from larger length scales to smaller length scales in solar coronal plasma, which is responsible for solar coronal heating.

Chemical Properties of Mixtures at WDM Conditions Characterized by Precise Spectroscopy Methods

Chongbing Qu (University of Rostock)

Warm dense matter (WDM) mixtures are widespread in brown dwarfs and the interiors of the planets. However, the extremely high temperature and high pressure pose severe challenges for its characterization of chemical reactions. X-ray absorption near edge structure (XNAES) and (X-ray scattering) XRS characterization methods are commonly used in condensed matter physics and structural biology. Newly capabilities at XFELs and synchrotrons now also allow using these methods for WDM. Possibilities of XNAES and XRS for characterizing chemical reactions in WDM will be discussed based on the latest measurements from EXFEL and ESRF in light of recent measurements at EXFEL and ESRF.

Numerical Simulation of Experiments for X-Ray Diagnostics of Pulsed Plasma

Aleksei Skobliakov (Institute for Theoretical and Experimental Physics of NRC «Kurchatov Institute», Moscow, Russia;)

Grazing-incidence spectrograph are used to record soft X-ray spectra of pulsed plasma radiation (for instance, in experiments with high-power lasers or Z-pinches). The main problems that prevent reliable qualitative and quantitative reconstruction of the initial spectra from the data, obtained in the registration plane of the spectrograph (detector plane) are the superposition of signals from different diffraction orders and the complex form of the instrumental function of the spectrograph, which depends on the wavelength of the incidence radiation. This problem does not have a trivial analytical solution. The construction of a full-scale model of the X-ray spectrograph allows one to calculate the instrumental function of the device which can be used to reconstruct the initial X-ray spectrum.
The simulation takes into account the probabilities of reflection in the diffraction orders after interaction with the diffraction grating, taking into account the surface profile of the diffraction grating [1,2,3].

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Probing of Exotic States in Hadron and Heavy Ion Collisions

Mikhail Barabanov, Adam Kisiel (WUT/JINR)

The near threshold production experiments in $\sqrt{s}_{nP} \sim 8GeV$ energy range with proton-proton and proton-nuclei collisions with $\sqrt{s}_{nP}$ up to $26GeV$ and luminosity up to $10^{32}cm^{-2}c^{-1}$ planned at NICA may be well suited to test this picture for the X(3872) and other XYZ mesons. Their current experimental status together with hidden charm tetraquark candidates and present simulations what we might expect from A-dependence of XYZ mesons in proton-proton and proton-nuclei collisions are summarized.

Wide-Range Models of Transport and Optical Properties for Subpicosecond Laser-Metal Interactions: Current Status and Problems

Pavel Levashov (JIHT RAS)

Subpicosecond laser pulses of moderate intensity are widely used in scientific, industrial and medical applications. In comparison to nanosecond pulses, a subpicosecond timescale of laser energy deposition makes it possible to ablate materials more effectively as the energy dissipation due to thermal diffusion decreases. Traditionally, a two-temperature hydrodynamic model is used for the simulation of single-pulse ablation of metals. The hydrodynamic model is closed by a number of constitutive two-temperature relations: equation of state, electronic heat conductivity, electron-ion coupling; also, a number of kinetic models may be used to describe the processes of nucleation, fragmentation, ionization, etc. In the case of multi-pulse ablation, the model should account for not only the laser light interaction with a target but also the propagation in the plume generated by previous pulses. Solving the Helmholtz wave equation for the laser electric field envelope, the absorption and reflection are calculated for an arbitrary profile of permittivity, which is a function of thermodynamic parameters obtained from the hydrodynamic equations [1]. Thus, two-temperature models of electronic transport and optical properties are required up to temperatures 10-100 eV and densities between 0.01 and 10 of the normal one. Currently such rather crude models exist only for a few metals [2]. The reason is that the specified region of strongly coupled and degenerate plasma is currently not covered by existing average-atom models while ab initio models such as quantum molecular dynamics are able to make calculations in a restricted range of densities and temperatures; besides ab initio simulations are very time-consuming. Therefore, future efforts should be spent to improve modern average-atom models and create a bridge between the chemical picture description and condensed-matter theories. Only in this case it will be possible to create reliable wide-range models of transport and optical properties and improve the current situation with theoretical description of laser experiments and technological processes.

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Stripping of Heavy Ion Beams Using Laser Ablated and Pinch Plasmas

Gerard Rodrigues (Inter University Accelerator Centre)

The stripping of heavy ion beams leading to higher charge states or fully stripped ions are required in particle accelerators for subsequent acceleration or user experiments such as Heavy Ion Driven

Inertial Fusion (HIDIF). Energy loss measurements of swift heavy ions (5–6 MeV/u) in a laser ablated carbon plasma [1] revealed a higher stopping power than corresponding gaseous and solid state matter. In fully ionized plasmas, the ion beam does not attain the equilibrium charge state as the stopping power of a dense free-electron gas slows down the ion in a shorter time before reaching the charge state equilibrium due to less probable recombination processes associated with free electrons. As a result of these ionization processes, the effective charge state of ion beam increases, even leading to probably fully stripped ions. One of the FAIR project [2] design beams is $^{238}U^{28+}$ for allowing higher particle densities at synchrotron injection, and passing such a beam through a dense plasma stripper or laser ablated plasma might allow for stripping to higher charge states. Recently, the plasma physics group at Institut für Angewandte Physik, Frankfurt, Germany have tested their theta pinch plasma device [3] by injecting a 3.6 MeV/u Au^{26+} ion beam through a hydrogen plasma having electron density in the range of $1 * 10^{16} cm^{-3}$, achieving much higher charge states as compared to using a cold gas. The interaction of heavy ion beams with plasmas will be evaluated using state of the art simulations in energy regimes ranging from 0.05 to 1.5 GeV/u for ^{238}U in order to propose such an experiment possibility at FAIR.

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The Non-Linear Complete Absorption Phenomenon for High-Power Microwave in a Plasma Filled Waveguide

Yakov Krasik, John Leopold (Physics Department, Technion), Yang Cao (Physics Department, technion), Yuri Bliokh (Physics department, Technion)

We present the first experimental observation of non-linear complete absorption of a K-band high-power microwave (HPM) pulse (1.2 GW, 0.5 ns, 25.6 GHz)1,2 in a plasma-filled waveguide. In the plasma-filled waveguide, electrons in the plasma being pushed towards the waveguide wall due to the ponderomotive force of the HPM pulse, create a potential positively charged well where the remaining electrons oscillated in the HPM pulses field. At near critical plasma density, where the plasma density dependent waveguide cut-off frequency is near to the HPM pulse frequency, the group velocity of the pulse decreases. Thus, trapped electrons have sufficient time to collide with ions and their regular field-induced oscillation motion becomes chaotic and thermal. Consequently, all the energy of the microwave pulse transfers to the kinetic energy of electrons. This nonlinear complete absorption phenomenon of HPM pulse is absent when pulse power is low, and the potential well does not form in the waveguide. The experimental result is confirmed by particle-in-cell (PIC) simulations

Characterising Insulator-Metal Transition of Hydrogen With Spectrally Resolved X-Ray Scattering

Divyanshu Ranjan (Helmholtz-Zentrum Dresden-Rossendorf)

The giant planets have dominated the numbers in the ever-increasing list of exoplanets. Efforts to understand the internal structures of these giants have been going on for a few decades. There have been numerous experimental and theoretical endeavors, but there is still a long way to go for a proper understanding of the interiors. The insulator-metal transition in hydrogen is an important phenomenon to understand interiors of gas giants like Jupiter and Saturn and the physical and chemical behavior of highly compressed condensed matter. We discuss a potential approach to characterize the formation of metallic hydrogen in dynamically compressed plastic samples by spectrally resolved X-ray scattering. With the help of time-dependent density functional theory (TDDFT) calculations and data collected in a previous experiment at European X-ray Free-Electron Laser (EuXFEL), we give an outlook of future experiments and canvass the possibilities with the drive laser system at EuXFEL.

Energy Relaxation and Electron Phonon Coupling in Laser-Excited Metals

Jia Zhang (Helmholtz-Zentrum Dresden - Rossendorf e.V.), Jan Vorberger (HZDR)

The rate of energy transfer between electrons and phonons are investigated in two differently complex metals, namely the simple metal aluminium and the transition metal copper. In order to reasonably take the electronic excitation effects into account, we adopt a finite temperature DFT and DFPT method to determine the T_e-dependent total and partial Eliashberg functions and electron phonon coupling factors. We demonstrate limits of the usual $T = 0$ calculations by comparison with various existing theoretical results. Our present work provide a rich perspective on the phonon dynamics and this will help to improve our insight into the underlying mechanism of energy flow in ultra-fast laser-metal interaction.

Experimental Investigation of the Sub-Picosecond Laser Interaction With Low Density Foams on the PHELIX Laser System.

Jakub Cikhardt (Czech Technical University of Prague (CTU)(CTU)), Olga Rosmej (GSI, Darmstadt), Nikolay Andreev (JIHT RAS), Natalya Borisenko (P. N. Lebedev Physical Institute, RAS, Moscow, Russia), Nikolai Bukharskii (National Research Nuclear University MEPhI), Marc Günther (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Mikhail Gyrdymov, Joachim Jacoby, Parysatis Tavana (Goethe University), Sero Jakob Zähter (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

Direct laser acceleration of electrons in plasma of near critical density was used for efficient generation of x-rays. In experiment, a low-density foam (2-5 mg/cm^3) with a thickness of (300-1500) µm was pre-ionized by a nanosecond laser pulse, which triggers a super-sonic ionization wave. Then the formed near-critical plasma is irradiated by the main laser pulse with a length of 700 fs and energy of around 70 J. The main pulse is focused to the spot with an intensity on the order of $10^{19} W/cm^2$. This workshop contribution is focused on the keV x-ray measurement in the most recent experiments in October and November 2021. The x-ray diagnostics is based on IP and semiconductor detectors in combination with Ross-filter pairs and various sets of photon absorbers. Such diagnostics allows us to obtain information about the generated x-ray flux, energy spectrum, and other features which are necessary for both basic research and applications.

Generation of High Energy Electrons and Protons in Interaction of Relativistic Laser Pulse With Foams of Sub-Mm Thickness

Mikhail Gyrdymov (Goethe-University, IAP, Frankfurt)

We report new results on acceleration of electrons and protons by relativistic laser pulses obtained the experiment on the PHELIX facility in October - November 2021. As a target a 2-5 mg/cc 300-1500 µm wide TCA foam was used. In addition, foams were used in various combinations with Au-foils, polystyrene and mylar films. For the experiment, the following laser parameters were set: ns-prepulse with length 3 ns and 0.3-3% energy of the main pulse to pre-ionize the foam target, 700 fs main pulse with a peak intensity of 1-3·10^{19} W/cm^2.
Various diagnostic methods were used in the experiment to characterize energy and angular distributions of accelerated electrons and protons. Electron energy distribution in forward and backward directions were measured by means of three 0.99T magnetic spectrometers with imaging plates (IP) used as detectors. Angular distribution of super-ponderomotive electrons with E > 3.5 and 7.5 MeV was measured by means of cylinder stack. For proton/ion measurements, both RCF-stacks and magnetic spectrometers placed in forward and backward directions to the laser axis were applied. During the experiment a new multilayer imaging plates method was approved to evaluate the proton spectra. The results correlate with the results of the RCF diagnostics.
Energy distribution, divergence and number of accelerated electrons and protons showed a dependence on the plasma density, which in turn was determined by the intensity of the ns pulse and the delay between the ns and sub-ps pulses of relativistic intensity. By increasing the intensity of the ns-pulse, we could observer a transition from Maxwellian energy distribution of electrons characteristic for DLA (direct laser acceleration) to strongly non-Maxwellian with 2-3-time lower divergence angle. In the case of protons, the highest cut-of energy and well-collimated proton beam was measured for the case of foam + Au-foil combination. The electrons were then accelerated up to 100 MeV and the protons up to 30 MeV at 10^{19} W/cm^2 laser intensity.
Finally, an application of the high-current electron beam with up to 50 TGy/s dose rate in radio oncology (flash effect) was demonstrated. This makes the development of the source of high-energy high-current electrons on the base of low-density foams very promising for experiments in radiation therapy.

EMP Measurements at VEGA

Michael Ehret (CLPU), Luca Volpe (CLPU), Giancarlo Gatti (CLPU), Massimo De marco (ELI Beamlines)

We present and compare experimental studies of electromagnetic pulses (EMP) produced by the interaction of relativistic laser pulses at intensities of several 1020 W/$\mathrm{cm}2$ with solid density targets. Passive calibrated B-field antennas with large bandwidth from 9 kHz to 400 MHz are used to detect electromagnetic pulses and excited cavity modes triggered by the laser-plasma interaction.
Both high-power 30 fs lasers, VEGA-2 with 200 TW and VEGA-3 with 1 PW, were deployed to discharge targets by hundreds of nano Coulomb. The escaping relativistic electrons trigger successive return current dynamics in the target and strong electromagnetic fields in the interaction chamber.
Building upon the study, we present prospects for a target geometry mitigating EMP and potentially applicable to particle beam collimation.

Stimulated Raman Scattering Coupled With Decay Instability in a Magnetized Plasma With Hot Drifting Electrons

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Coupling of stimulated Raman back-scattering to decay instability with hot drifting electrons in a magnetized plasma is investigated. We consider the stimulated Raman scattering (SRS) of the laser beam in a magnetized plasma. This creates a downward shifting electromagnetic wave and a forward-moving plasma wave via parametric coupling. In this process, the plasma wave generated from SRS decays into an ion-acoustic wave and a secondary Langmuir wave with a longer wavelength that propagates backward. The amplitude of Raman instability is reduced by this energy diversion and damping of the main Langmuir wave by drifting electrons. The plasma wave is dampened resonantly at a higher rate in the presence of drifting electrons, and the stimulated Raman scattering decreases considerably.

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