EMMI Workshop Report: Plasma Physics at FAIR

An update to the Scientific Case for Plasma Physics at FAIR

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The plasma physics department of GSI organized a workshop on plasma physics at FAIR on June 21th-23th 2017. The Extreme Matter Institute (EMMI) sponsored the workshop. Participation from the international plasma physics community was solicited to discuss topics in plasma physics and high energy density science with a view to planning the plasma physics science program for phase "0" at FAIR. A summary of the main topics of the meeting follows.

Group picture of the workshop participants

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1 Workshop Summary and Recommended Actions

High Energy Density Physics (HEDP), the study of matter under extreme conditions of temperature and density, is a developing multidisciplinary field that is expanding the frontiers of many scientific disciplines. HEDP cuts across many traditional fields of physical science, including astrophysics, cosmology, nuclear physics, plasma physics, laser science, and material science. It is a scientific enterprise where theory and experiment intersect to extend our conceptual framework of the universe. Potential applications range from improving our understanding of planetary structure, to creating new material states of matter, to fusion energy.

HEDP, along with atomic physics, biophysics and materials research, forms one of the 4 major scientific pillars for the Facility for Antiproton and Ion Research (FAIR) presently under construction at the GSI site in Darmstadt. These pillars will utilize the unique capabilities of FAIR to grow and develop forefront scientific understanding through the first half of this century. With these perspectives in mind, a workshop on HEDP and Plasma Physics at FAIR was held at GSI Darmstadt on June 21th-23th, 2017. The principal purpose was to assess the status of high energy density (HED) research worldwide with a view to identifying HED and plasma physics themes at FAIR. That is, areas of HED and plasma physics research where FAIR can provide unique capabilities to advance scientific understanding. The workshop was attended by 120 scientists representing a broad range of international HED research from 12 nations. The meeting was organized to provide an overview of international HED research with a view to building a collaboration of future FAIR scientific users.

The identified themes for FAIR HEDP and Plasma Physics research fall into the following areas:

- **Properties of materials driven to extreme conditions** of pressure and temperatures **relevant to planetary science** (earth and super-earth like planets, giant gaseous planets, brown dwarfs) by the FAIR heavy ion beams.
- **Shocked matter and material equation of state** (EOS) studies driven with FAIR heavy ion beams, laser drivers, gas-guns, electromagnetic drivers and explosive drivers, using advanced radiographic tools, in particular PRIOR.
- **Basic properties of strongly-coupled plasma** (energy/particle transport, radiation properties, particle stopping properties, etc.) created with heavy ion beams (e.g. HIHEX and LAPLAS) and lasers.
- **Nuclear Photonics**: excitation of nuclear processes in plasmas, laser-driven particle acceleration and neutron production, and neutron-based diagnostics with application to understanding FAIR-produced HED matter.

Prominent scientists were invited to give overviews of these scientific themes along with their views on where FAIR-based research can make unique contributions to HED physics in the future. A thematic synopsis of these talks follows.

Summary of Recommended Workshop Actions

- Developing FAIR Plasma Physics Collaboration
- Phase-0 Scientific Program
- FAIR commissioning and first experiments

Properties of materials driven to extreme conditions relevant to planetary science

David Riley summarized several outstanding HEDP questions in planetary science. For example, the postulated existence of diamond layers in large planets like Uranus [1], the generation of magnetic fields in large planets [2], and the metallization of hydrogen under extreme conditions of pressure and temperature. The motivation was to provide planetary science with the experimental data necessary for computational model development and validation and improve present theories to predict large-planet properties. The strong coupling between particles, the degeneracy of the plasma, and its partial ionization challenges the warm dense matter theory that underpins the models used to calculate planetary properties. Validation of computational models will require experimental data under the HED conditions present in large planet interiors.

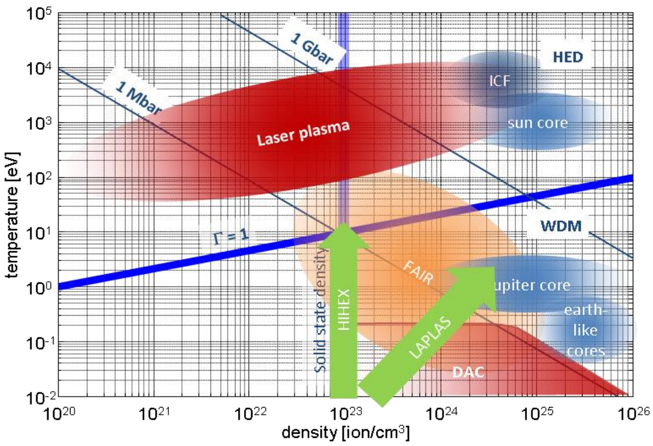

Figure 1: density-temperature diagram showing HED states achievable at FAIR, their relevance to planetary physics applications and complementarity with other drivers. The HIHEX and LAPLAS refer to two experimental schemes that will be developed at FAIR.

Accessing warm dense matter conditions in the laboratory presently utilizes a variety of techniques including shock drivers that are laser-driven, Z-pinch-driven or explosive-driven. These techniques reach pressures in the range of 1-10 Mbars and are well established. As an alternative, volumetric heating from highly penetrating photon (x-ray) sources and particle beams (electrons, ions) provide several advantages. This generates, for example, warm dense matter in local thermodynamical equilibrium and with samples large enough such that these systems are relatively uniform and evolve on the nanosecond to microsecond time-scale. These conditions enable accurate EOS determination and provide enough time for processes like superheating [3] to develop and become visible. Here, the use of heavy-ion beams at FAIR for creating WDM states offers a unique and complementary approach to the other WDM drivers , as shown in Figure 1.

Ronald Redmer focused on the specific topic of matter under planetary conditions. Warm dense matter, found in the interior of large planets or in man-made plasma like those of the National Ignition Facility (NIF) in the USA, share the same need for Equations of State in the 1 to 100 eV range, pressures in the megabar to gigabar range, and densities between 1 and 10 times solid-state density. Giant planets are relatively large astronomical objects with masses up to 10 000 times the mass of the earth and mass to density scaling laws that are dependent on their chemical composition. These giant planets are presently understood as complex systems where material behavior including conductivity, equation of state (EOS), and mass-flow are used to explain the generation of magnetic fields (dynamo effect). The materials found in large planets

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[1] Ross et al., Nature **292,** 435 (1981)

[2] Stevenson et al., Rep. Prog. Phys. **46,** 555 (1983)

[3] Luo and Ahrens. Physics of the Earth and Planetary Interiors **143,** 369-386 (2004)

include H, He, C, N, O, Fe, Si along with molecular combinations of these elements. The simulation of the microscopic and mesoscopic properties of these materials, under planetary conditions, requires sophisticated simulation codes, like molecular dynamics (MD) codes, based on distribution function theory (MD-DFT), that predict parameters like viscosity, thermal and electrical conductivity etc.. These codes are essential to build planetary models but require experimental validation. Again, use of heavy-ion beams at FAIR offers a unique and complementary approach to the other WDM drivers to access these WDM conditions.

Shocked matter and material equation of state

Igor Lomonosov stressed that studying the equation of state of energetic materials has many applications in applied science and technology. Examples discussed included fission and fusion power plants, space debris mitigation, and meteoroid impact prediction and modelling. Dynamic experiments enable studying the temperature of materials in the eV range as a function of pressures in the 10-100 Mbar range, reaching the melting point or evaporation point conditions for these materials. Depending on the scheme used for dynamic compression, equations of state on the isentrope or isobar can be created and measured.

As discussed by **Ronald Redmer**, diamond anvil cells (DAC) can access modest pressures and temperatures (up to 2 Mbar) for material structure and EOS studies. For some cases, dynamic compression can reach up to 10 Mbar. Fourth-generation light sources employing free electron lasers (FELs) use coherent x-rays to probe the compressed DAC matter and provide data to benchmark molecular dynamics codes. The DAC technique, however, cannot access the WDM state.

Igor Lomonosov also presented the data range available through static DAC measurements and their relevance to WDM studies for conditions moderate in comparison to the other drivers. Dynamic compression using nuclear explosives have proven to be very effective in reaching ultra-high pressures above one gigabar in the second half of the nineteenth century. Nevertheless, creating and probing matter in the HED state remains an international scientific priority.

The FAIR facility will be able to generate the world's highest heavy-ion beam current. As such, this capability enables the creation of unique warm dense matter states for scientific investigation. The "Heavy Ion Heating and Expansion" (HIHEX) scheme, where matter is isochorically and uniformly heated by an intense heavy ion beam, is one FAIR-based technique for WDM EOS studies. This experimental scheme has already been tested at the GSI-HHT cave, although with lower beam intensities. Many groups in Russia and Germany have experience and interest in this technique for EOS studies, specifically utilizing the improved beam parameters at FAIR. Another use of the FAIR beams is to launch shock waves as reported by **David Riley**, where the ion beam is stopped in a high-Z material and the expansion creates a shock (compression) in a probe located at the side. This scheme, originally proposed by the HEDgeHOB collaboration, remains another potential shock-driver technique.

Given FAIR heavy ion beams will be used to create WDM or other extreme states of matter, a complete set of probes and diagnostics will also be required. FAIR HED and plasma physics experiments must operate in a "pump-probe" configuration and this will require a powerful backlighter source. As presently envisaged, the "Helmholtz Beamline", will provide the high-energy laser for backlighting and other probing. The Helmholtz Beamline is on the roadmap of infrastructure of the Helmholtz society but remains in the planning stage. Without a powerful laser backlighter, the HED research at APPA will be significantly impacted.

Basic properties of strongly-coupled plasma

Research on dense plasmas at FAIR will also, and particularly, allow addressing the fascinating fundamental aspects of correlated many-body quantum systems. Plasmas at warm-dense matter conditions pose a formidable challenge to theory. Due to strong coupling of the ion system the statistical framework of traditional plasma physics is no longer applicable and perturbative methods fail. In addition, partial degeneracy of the electron component requires a quantum mechanical treatment. Concomitantly, strong coupling and electron degeneracy give rise to the rich and exotic behaviour of these matter states, such as phase transitions and metallization. As example, **Ronald Redmer** elaborated on the still outstanding issue of the metallization of hydrogen. Recent experiments in shock-compressed D_2 suggested an insulator-metal transition at pressures significantly higher than predicted by DFT-MD calculations. The latter showed a strong sensitivity to the choice of the exchange-correlation functional. Accurate experimental data in the warm-dense matter regime thus help elucidate the role of assumptions in modern state-of-the-art dense matter theory. **Siegfried Glenzer** presented measurements of plasmon scattering from aluminium samples, rapidly heated by intense x-ray pulses. Plasmon shift and width are only poorly described by the usual Born-Mermin-approach and indicate a non-linear damping component and a non-Drude-like conductivity. Also here, the advanced HSE-functional provided a significantly enhanced agreement between theory and measurement. **Victor Mintsev** showed early measurements of electrical conductivity of noble gases in the WDM regime, where the classical Spitzer-theory fails, and now modern ab-initio methods are employed. He also presented one of the experimental proposals within the FAIR plasma physics collaboration, to study molecular fluids (such as H_2 and N_2) at Mbar pressures, where they are predicted to undergo phase transitions to various exotic (high-conductive, metallic, polymeric) phases. **Igor Lomonosov** reminded in his talk the problem of measuring the critical points of many metals. Theoretical predictions vary widely and experimental measurements are very difficult. Furthermore, the prediction of non-congruent phase transitions in composites is a topic of fundamental thermophysical interest.

The topic of the ionization potential depression (IPD) in strongly-coupled plasmas was addressed in the talk by **Tilo Döppner**. This topic has attained significant attention and motivated strong theoretical activities after experiments at isochorically heated aluminium samples at the first free electron laser LCLS at Stanford had shown significant discrepancies with the widely used IPD model. **T. Döppner** presented results from a campaign in the Discovery Science Program at the National Ignition Facility, measuring the ionization balance at ultra-high densities, exceeding 30 g/cc by spherical compression in a laser-driven hohlraum. Measuring the ionization balance by x-ray scattering indicates a significantly higher ionization than predicted by standard theories of IPD. This clearly shows the need for an improved understanding and treatment of atomic physics in such strongly coupled systems. Such strongly coupled degenerate plasmas, although at lower density, can be produced with very high quality (homogeneity, equilibrium conditions) by heavy-ion heating of tamped foils. **Dimitri Khaghani** showed on-going activities to prepare high-resolution x-ray transmission spectroscopy to measure continuum lowering in such plasmas in the FAIR phase-0 program.

Nuclear Photonics

Nuclear Photonics encompasses a rapidly evolving field of research enabled by high-power, short-pulse laser facilities together with targets designed for the production of intense particle or photon beams. The application of these intense beams promises significant advantages for the diagnosis of FAIR-generated matter at extreme conditions. For example, laser-generated protons, neutrons, and X-rays can be directly employed for radiographic imaging. Intense laser-generated and moderated neutron beams can also be employed for measuring temperature of shocked or isochorically-heated matter using neutron resonance spectroscopy. Nuclear Photonics is an important area for collaboration with other facilities researching extreme matter worldwide. Several applications and opportunities for FAIR were discussed in the talks summarized below.

2 HED at GSI/FAIR

2.1 Status of the plasma physics collaboration

The collaboration for High-Energy-Density Science at FAIR (HED@FAIR) was founded on February 3rd 2017 during the 37th international workshop on Physics of High Energy Density in Matter in Hirschegg Austria.

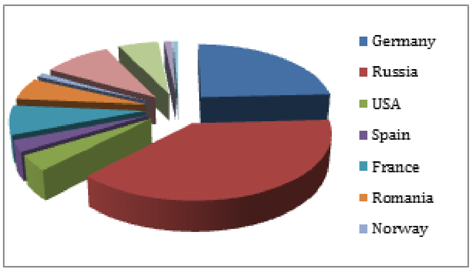

Figure 2: 178 members from 11 countries have joined the HED@FAIR collaboration as of August 2017

The HED@FAIR collaboration that focuses on the experimental program that will be conducted at the dedicated plasma physics beamline in the APPA cave of FAIR, is basing its program on the preliminary work of the HEDgeHOB and WDM collaborations and seeks to unify the effort of both groups into a single goal. The collaboration is organized around a collaboration board that is the steering body of the collaboration and an executive board, which is responsible for the representation towards the outside and the daily business of the collaboration. The collaboration board, chaired by V. Bagnoud, elected during the workshop Alexander Golubev as chair of the executive board and collaboration spokesperson.

The collaboration is open to any scientist that is interested in participating in the definition, development and realization of the HED program at FAIR. In addition, the collaboration HED@FAIR aims to play an ever growing role in the interim science program (the so-called phase 0) that breaches the gap between the present and the startup of FAIR in 2024. In this view, the collaboration will use the existing GSI facilities (PHELIX, the Z6 target station at the UNILAC, and the high-energy cave HHT at the SIS-18) to prepare the scientific program of the APPA cave.

2.2 FAIR facilities

The sessions of the workshop addressing the FAIR facilities covered the progress in the FAIR project as well as R&D contributions from collaborating universities around GSI and theoretical support from JIHT in Moscow.

At first, P. Giubellino, the scientific director of GSI and FAIR, reported on the status and current development at GSI/FAIR. The FAIR project is on track, as best illustrated by the ground breaking ceremony for the synchrotron tunnel on July 4th this year and the integrated project management plan, that includes planning for the FAIR buildings, the accelerator, as well as the detectors for experiments. According to this plan, the HED collaboration expects to start bringing first components in 2021 into the cave and do the commissioning without beam in late summer 2024. P. Giubellino emphasized the importance and uniqueness of synergistically exploiting ion and laser beams for dense plasma research. Plasma physics is about pump-probe experiments, hence the GSI SIS18 and the upcoming FAIR SIS100 synchrotron, in combination with bunch compression capabilities to produce intense, short (<70 ns) beam pulses, are ideal plasma physics drivers matched to the current and future needs of the community. High-energy lasers, like PHELIX at GSI or the envisaged Helmholtz Laser Beamline at FAIR, offer powerful diagnostic tools for HED research. Therefore merging laser and accelerator technology is a highly strategic research direction for FAIR and also for Helmholtz.

Particular attention was paid to the upcoming beam time 2018/19, with the restart of the intensity-upgraded UNILAC/SIS18 facility including storage ring ESR and the newly installed CRYRING. PHELIX operation will continue on the present level. From 2018 till the start of commissioning of SIS100 synchrotron 2021, there will be about 3 months of beam time per year for the FAIR Phase 0 program.

Peter Spiller, leader of the subproject SIS100/SIS18 at FAIR, reported on the status of the accelerator, especially on the upgrade of the existing SIS18 and the progress in the realization of SIS100. The SIS18 upgrade program, as originally defined, will be completed beginning of 2018. Further upgrade measures to stabilize the dynamic vacuum in a 3 Hz operation mode have been proposed and need to be implemented. Additional effort has been taken to improve the operation for the user program in FAIR phase 0, e.g. a high harmonic micro-spill smoothing cavity will be tested in 2018. Civil construction for the „Link existing facility" is running and progressing well. Concerning the SIS100, contracts for major system components have been placed. The delivery and testing of accelerator components is underway.

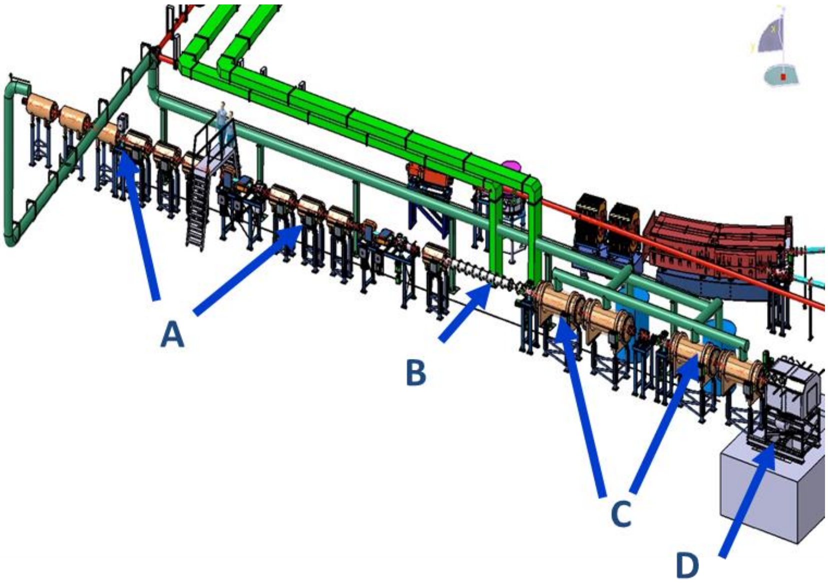

Figure 3: A 3-D model of the planned plasma physics beamline in the APPA cave at FAIR. A: beam-matching section and diagnostics; B: wobbler; C: focussing magnets; D: target chamber.

S. Neff, the resource coordinator of the HED@FAIR collaboration, presented the status of the facility for the HED experiments at FAIR. This facility is designed to exploit the world-wide unique capabilities for HED experiments at FAIR. The baseline design of a flexible ion beam line, as shown in Figure 3, is finished and approved by FAIR. This beam line will allow for a wide variety of experiments using uranium (HIHEX, LAPLAS) to protons (PRIOR) in the first phase of FAIR. All technical design reports, except for the matching beam section, are approved. The construction of the superconducting final focusing system has started at IHEP. Beyond the modular start version of FAIR, achieving the full performance of the experimental capabilities will, however, require additional funding.

To illustrate the foreseen experiments at FAIR in the APPA cave with annular beams, **Naeem Tahir** presented in his talk new theoretical results on generation of earth-like planetary interior conditions at FAIR[4]. Simulations have been made for 75-100 ns, 1 GeV/u U-beam that will be available on Day 1 ($5 \cdot 10^{10}$ ions/bunch) and in the FAIR full operation mode (10^{11} -5. 10^{11}). These calculations show that the LAPLAS-scheme using hollow beams creates highly-compressed solid and liquid iron states. Measurement of transport properties like thermal and electrical conductivities, and viscosity of the iron samples under extreme conditions will be possible. In the frame of future experiments, studies of Richtmyer-Meskov and Rayleigh-Taylor hydrodynamic instabilities are also proposed.

M. Roth gave an overview about the R&D activities of the German universities within the frame of BMBF-Verbundforschung and concerning first-day experiment diagnostics at FAIR. His talk covered new development of photon and particle diagnostics. For PRIOR, high-performance scintillators and cameras and have identified and these components should be tested at HHT. The key questions will be temporal and spatial resolution, efficiency, radiation damage and EMP resistance. For the laser driven X-ray diagnostics, TU Darmstadt is working on two subjects: the development of an actively cooled main amplifier with a sandwich design, where a thin coolant layer flows between two glass slabs enabling an increase in the laser repetition rate to one shot every 10 minutes; and optimizing narrow band X-ray yield for XRTS by using micro-structured targets like needles, pillars or grooves. Experiments at different laser facilities have shown reduced reflected laser energy and enhanced Kα- emission from this class of targets.

N. Andreev gave an overview about the theoretical support of FAIR relevant experiments at the Joint Institute for High Temperature (JIHT) in Moscow. He presented a wide range of models starting with laser interaction with matter, laser electron acceleration for backlighting WDM, and the generation of Kα X-rays in foils at PHELIX. JIHT, in support of the HED research community, has developed a wide range of models for laser iteration with matter that can be used to better understand laser-plasma production, e.g. at PHELIX. For example, hot electron generation in low-density targets has been investigated as a high current source of accelerated electrons. Laser electron acceleration, where a short and intense laser pulse is at grazing incidence to a solid target, provides a bright source of fast electrons in a hundred MeV energy range. Models of electron temperature and Kα photon generation by hot electrons, produced by a sub-picosecond relativistic intense laser pulse, are in a good agreement with measurements.

Finally **A. Schönlein** from the Goethe-University Frankfurt presented some of the envisioned applications of high resolution X-ray fluorescence spectroscopy for HIHEX-experiments at FAIR. For the investigation of fundamental properties of matter under extreme conditions within the HIHEX scheme, the energy density distribution in the target, deposited by a heavy ion beam, is a key parameter for numerical simulations of hydrodynamic target response. Therefore they presented the development of a scintillator and fiber-based X-ray fluorescence detector for FAIR to measure the target expansion, the ion beam intensity distribution on the target as well as the number of interacting projectiles. First experiments at the UNILAC showed the applicability of the scheme, where the dependence of the X-ray fluorescence yield on the number of interacting projectiles and target material has been successfully investigated.

[4] N. Tahir et al., The Astrophysical Journal Supplement Series **232** (2017)

2.3 Phase 0 research at GSI

In 2018, GSI will complete the upgrade of the SIS-18 accelerator ring necessary for seeding FAIR. After this shut-down period, the SIS-18 will gradually be driven to higher and higher intensities. FAIR and GSI have decided to drive a limited research program during this start-up phase to exploit the improved capabilities of SIS-18 and test the necessary equipment from the FAIR collaborations. This period is called “Phase 0”. For HED@FAIR, the phase 0 means running experiments at GSI’s existing facilities: PHELIX, the Z6 target station of the UNILAC, and the high-energy cave at the SIS-18 – HHT.

Stefan Götte reported about the experimental capabilities of the PHELIX facility. Since its commissioning in 2008, PHELIX has developed into a well-established user- facility making a significant contribution to the field of plasma and atomic physics. He discussed the latest evolution of the laser parameters, the procedure of the experimental project application and the user support. For phase 0, in addition to user operation, parameters like the laser focus quality, the repetition rate operation, and the commissioning of a VISAR system at Z6 experimental area, for laser-driven shock experiments, will be improved. In the future, the construction of the beam lines to the HHT experimental areas, an upgrade of the facility at Z6, and the support to develop the nanosecond 100-J laser at FAIR are planned.
In addition to PHELIX, GSI plans to restart its experimental program at the HHT cave..
The GSI accelerator will provide beam time for the user community in limited amounts of about 3 months per year during phase 0. The HED@FAIR collaboration will use this opportunity to commission the second PRIOR prototype (PRIOR II), which is based on electromagnets (see section 0 of this document:

Proton microscopy, PRIOR, and the round table discussion). This technical implementation of the proton microscope is more robust against radiation than the one based on permanent magnets and therefore should perform for a longer time in the APPA cave environment without significant maintenance costs.

Finally, it is expected that ion intensities above 10^{10} ions/bunch will be obtained in the near future at SIS-18 and will be available at HHT. Such intensities will be sufficient to achieve quasi-isochoric heating of a dense target and isentropic expansion (HIHEX). This will enable the measurement of EOS and transport properties for non-ideal plasma and warm dense matter (WDM).. However, this requires volumetric diagnostics as discussed in details in section 5: Round table discussion: PHELIX at HHT.

3 Reports on HED research worldwide and its applications

Plasma physics research is being conducted at many facilities worldwide. Researchers active in the field came to the workshop to present the current activities and capabilities of these facilities, underlining the complementarity of approaches between theirs and FAIR.

3.1 Plasma Physics Research at other facilities

HEDP studies span a range of science that is highly interdisciplinary. As such, this requires numerous interconnections to existing and developing major facilities; no single facility can fully serve the HEDP broad research agenda. Creating and probing matter under extreme conditions, across many orders of magnitude in density, temperature, and temporal extent, necessitates tailoring said research to the specific capabilities of a given facility. So will be the case for FAIR, where the unique pump-probe characteristics of APPA will support a range of HED experiments.

The workshop session on plasma physics research at other HED facilities gave important input onto the relevance of the HED program at FAIR and its possible links to the international efforts at other laboratories. While it is beyond the scope of this report to fully assess international HED capabilities, the facilities represented herein provide a reasonable survey. Major facilities represented included the National Ignition Facility (NIF)-USA, the Linac Coherent Light Source (LCLS)-USA, Laser Megajoule (LMJ-PETAL)-France, NCDX-II and Bella-USA, HIAF-China, PALS-Czech Republic, ELI-Czech Republic, Titan-USA, PHELIX-Germany, LANSCE-USA, and MaRIE-USA. These facilities are shown on the world map of Figure 4.

Figure 4: HED facilities worldwide that offer a complementary approach to FAIR and that were represented at the workshop

The presentation by **Thomas Schenkel** from LBL Berkeley gave an account to present and planned activities at the NDCX-II induction linac and the Bella-i laser facility. Complimentary to the high-energy heavy-ion beams at FAIR the NDCX-II linac concentrates on low-energy but very intense beams on light ions (e.g. He+). Offering a pulse length of 2.5 ns and a peak current of ~2 A, a main emphasis is presently on the effects of high-flux, short ion pulses on solid state structures, and also energy loss under high-flux conditions. In the future, when higher intensities are reached, phase transitions and warm-dense mater will be in reach. Exciting perspectives also exist in the study of the synthesis of novel materials at the on-set of the warm dense matter regime. The Bella-I laser facility represents at present the highest repetition rate Petawatt laser. Operating at up to 49 J in 33 fs at 1 Hz, the laser can provide the most intense source of laser accelerated electrons (above 1 GeV) and ions. It will also deliver unprecedented intensities of Betatron x-rays for diagnostics. At present a phase 1 of experiments on ion acceleration is running. Combined with focusing devices it will provide a powerful tool for the preparation of warm dense matter. Once a beamline with short focal length will be commissioned intensities around 1022Watts per cm2 will be reached. This can open a new regime of laser acceleration as well as it can give the chance to see QED effects.

Dimitry Batani from the "Centre Laser et Applications" at the University of Bordeaux was concentrating on the complementarity and possible synergy between the projects at GSI/FAIR and the LMJ-PETAL project at Bordeaux. Despite the completely different characteristics of the laser and the ion beam driven plasmas a similarity was seen in the concepts of laser driven diagnostics. Development of laser driven secondary sources and novel techniques like XANES, X-ray radiography, and X-ray phase contrast radiography will be useful for both drivers. Short pulse and isochoric heating will address different aspects of the plasma phase diagram. It was stated that, as a complementary scenario heavy-ion prepared plasma in combination with laser diagnostic, acceleration and the creation of magnetic fields should "… write a new chapter in the HED physics"

Libor Juha from the PALS Research Center and the Institute of Plasma Physics of the Czech Academy gave a wide overview over present and future dense plasma physics at PALS and the ELI Beamlines facilities. Many excellent experimental results from the PALS laser (1kJ pulses with 300 ps duration at 315 nm) were shown. The importance of advanced diagnostics and secondary sources was emphasized. The status and an outlook on the ELI beamlines facilities and experimental areas were given. With a suite of laser driven sources covering x-ray to THz, and a maximum power density exceeding 10^{23} Watt/cm^2, the facility is striving for ultra-high fields and new access to astrophysical problems as well as applications in technology and applied sciences.

Rui Cheng from IMP CAS at Lanzhou gave an overview on the Warm Dense Matter oriented program at the planned HIAF facility in China. The key parameters of the accelerator complex are similar to the FAIR scope. As at FAIR, the scientific program is supporting different subjects, including nuclear physics and nuclear astrophysics as well as atomic und plasma physics. The time scale of the project is similar to FAIR. In the science program questions related to ICF, particular in context with the Chinese inertial fusion program at the SHENGUANG project, has a strong role. A wide research activity directed towards a study of the physics of WDM has already started. Very remarkable is the effort towards a High Energy Electron Radiography (HEER). Experiments have reached prove of principal with a high resolution and density resolution. In the planning a pulse duration of ~10 ps seems possible. The test platform is set up is under construction at the IMP at Lanzhou. Proton radiography and other diagnostic schemes are also under development. With the additional diagnostics HIAF will be highly competitive to FAIR.

Kurt Schoenberg, from the GSI Extreme Matter Institute (EMMI) and Los Alamos National Laboratory, presented an overview of Neutron Resonance Spectroscopy (NRS). NRS is a promising technique for measuring temperature in shocked or high-energy-density matter at the proposed Los Alamo MaRIE facility and at FAIR. Time and spatially resolved measurements of bulk-temperature of experimental samples are a critical need in dynamic materials research. Specifically, a technique is sought with temporal resolution capabilities of order 1 ns (shock transit time over the dimension of a typical solid grain) and as small as ~ 10 μm, although lesser resolution would still be valuable given present alternatives. NRS utilizes a broad-energy-band neutron beam to excite a nuclear transition, typically of order 20 eV. The Doppler-dominated absorption-line width in the transmitted neutron beam yields the sample temperature. The penetrating power of epithermal neutrons and the ability to localize a suitable dopant within the sample readily enables spatial and temporal resolution, provided the neutron fluence is sufficiently high.

NRS has been demonstrated at the Los Alamos Neutron Science Center (LANSCE) using moderated neutrons from a ~ 1GeV proton-driven spallation source.[5] However, spallation neutrons must be heavily moderated to be useful. This moderation process leads to neutron pulses with durations longer than desired, and assembly sizes that are very large and costly. Moreover, even for an instantaneous neutron pulse of finite energy spread, the ultimate time resolution is dictated by the spread in time of flight through the doped/resonant part of the dynamic sample for the neutrons with energies spanning the resonance width. This time spread is proportional to the flight time from the moderated (epithermal) neutron source. At LANSCE, the NRS targets must be placed ≥ 1 m away, which makes the time spread ~ 200 ns for the resonance line used (~ 20 eV).

An intense neutron-beam source driven by laser-produced intense deuterium (D) beams shows promise of greatly improving temporal resolution. For example, the Trident laser has produced a neutron beam with ~10^{10} neutrons in approximately 1 ns and in ~ 1 steradian, with a quasi-Maxwellian energy distribution of ≈ 2.7 MeV average energy. Neutron moderation from these lower energies can be done much faster than in

[5] V. Yuan et. al., Phys. Rev. Lett. **94**, 125504 (2005).

spallation sources with a much smaller moderator, providing a path to meeting NRS requirements. Nevertheless, significant development of the NRS technique remains in order to meet the neutron flux/fluence requirements and general experimental design for MaRIE-class dynamic experiments. These development activities provide a foundation for collaboration between MaRIE and FAIR shock-driven thermometry development. Specific areas for collaboration include:

- Developing compact, laser-driven neutron sources relevant for specific FAIR or MaRIE experimental configurations.
- Modeling of the effects of thermodynamic states on the neutron resonance profile, including proper inference of bulk temperature.
- Design of NRS first experiments, including achievable spatial and temporal resolution.

3.2 Research on Ultrafast Plasma

The session on ultra-fast plasma physics began with a presentation by **A. Phukov** (U. Düsseldorf) on nano-structured targets irradiated with ultra-short relativistic laser pulses. Advances in short-pulse laser technology have led to generation of high-contrast laser pulses with a laser pre-pulse level over 10 orders lower than the laser peak intensity. This allows irradiation of delicate high-aspect ratio nano-structures with intense laser pulses, preserving the target structure until the arrival of the laser-pulse. Highly computing intensive 3D particle-in-cell simulations show that this allows the laser light to penetrate into the interstitial space between the nano-structure, thus delivering laser energy at average densities far above the critical density. This results in a very efficient absorption (near 100%) of laser energy and the generation of extreme energy densities, corresponding to 100's of Gbar pressures – conditions prevailing in the center of the sun, reached otherwise only in inertial fusion scenarios. These simulations also show that cooling of these extremely hot states is dominated by x-ray radiation, which could yield record high conversion efficiencies of laser energy to x-rays. First experiments have already shown significant enhancement of x-ray line emission from these targets. This shows a promising path towards ultra-bright x-ray sources, enabling many x-ray based applications. Furthermore, simulations of individual nano-wires irradiated by ultra-relativistic laser pulses show strong magnetic fields, generated by return currents drawn along the wire. These fields produce a strong inwards cylindrical compression and eventually lead to a nano-scale Z-pinch.

A. Korzhimanov from the Institute of Applied Physics in Nizhny Novgorod talked about the perspectives to generate matter at high energy density conditions by rapid isochoric heating using laser-accelerated protons. Given the parameters of current (such as PHELIX, Omega EP and others) and upcoming (e.g. ELI beamlines L4 or the XCELS facility in Russia) high-energy short-pulse laser facilities worldwide, ranging from few hundred joules of laser energy in picoseconds up to several kJ at pulse durations below 100 fs, already simple scaling relations indicate that matter states with keV temperatures at Gbar pressures could be attainable by proton-heating. This offers a very intriguing path towards efficiently generating homogenous samples of high-energy density. More detailed calculations were presented, showing modifications due to non-linear effects, which require a self-consistent treatment of the particle stopping and material heating. At even higher particle beam flux density, calculations indicate that non-linear beam-plasma-interaction may become a major effect. While this in itself is a fascinating field at the crossing of accelerator and plasma physics, this needs to be taken into account in the design HED experiments.

O. Rosmej presented results from experiments at the PHELIX and the Jeti40 (Jena) laser systems, where thin metal foils had been irradiated with intense laser pulses at the highest available temporal contrast. Broadband spectroscopy was used to measure characteristic line emission of the entire K-shell spectrum, ranging from neutral K-alpha up to Ly-alpha, and further to the more energetic He-beta and He-gamma lines. The spectra indicate both heating to temperatures of order 1 keV, as well as high densities close to the density of solid. This heating can be explained by the interaction of energetic electrons, produced in the intense-laser matter interaction, while the target remains near solid density due to the high-contrast laser pulse. These findings were further corroborated by measurements of the escaping fast electrons by means of an electron spectrometer, and the emission bremsstrahlung radiation with hard x-ray spectrometers based on imaging plates, as well as on a highly-pixelated CdTe detector. The results are supported by particle-in-cell calculations, which show that besides hot electrons fractions at average energies of 10’s of keV and MeV, a significant amount of energy is converted to electrons at only 1-2 keV. These electrons carry about 2 orders of magnitude more charge than the more energetic ones, and they are responsible for depositing up to 10MJ/g in a 100nm thick layer of the target.

S. Glenzer gave a broad overview of activities at the Linac Coherent Light Source (LCLS) x-ray free electron laser at SLAC. The FEL can be used both to generate matter at HED conditions by ultra-fast energy deposition by photoelectric absorption, and to probe dense plasmas, e.g. created by an optical laser, with x-ray techniques such as x-ray diffraction and scattering. A variety of recent experiments that have resulted in high-impact publications was presented, such as accurate ion-ion structure factor measurements on strongly shocked aluminium, formation of lonsdaleite diamond in shocked graphite, or the phase separation in low-entropy shock-compressed CH-targets relevant to the conditions in giant ice planets. Developments towards high rep-rate targets based on liquid jets, and results from first experiments measuring equilibration rates showed the need for quantum kinetic theories to explain the electron-ion energy exchange observed in these experiments. Furthermore, high-resolution x-ray scattering spectra in the collective regime on x-ray laser heated aluminium foils revealed plasmon resonances significantly narrower than predicted by calculations in the Mermin-approach, including collisions by means of the Born approximation. Also, ab-initio MD calculations using as exchange-correlation functional the widely used PBE-functional fail to reproduce, while the more sophisticated non-local HSE-functional achieves an almost perfect fit to the data. Finally, an outlook was given to upcoming experiments within the “Discovery Science”-program at the National Ignition Facility (NIF), where such x-ray scattering experiments will be performed at ultra-high densities, approaching conditions as found in brown dwarfs.

3.3 Laser-based Plasma

High-energy nanosecond lasers are used worldwide as plasma drivers because of the versatility of such drivers. One of the most prominent high-energy laser facilities is the National Ignition Facility (NIF) that allocates about 10% of its available beam time to a discovery science program that is dedicated to academic access. Thanks to the symmetric geometry of the NIF setup, spherical compression can be achieved to reach high pressures after illumination of a spherical sample with the laser. In a recent experiment aiming at reaching high-pressures, a group of researcher belonging in part to the HEDatFAIR collaboration led by P. Neumayer and R. Falcone, compressed CH and Be capsules to about 30 g/cm^3 and reached electron densities of $\sim 10^{25}$ cm^{-3} using the x-rays generated by converting the NIF energy in a hohlraum. This experiment, reported by **Tilo Doeppner** at the workshop, employed x-ray Thomson scattering (XRTS) as a diagnostic to quantitatively measure the elastic and inelastic components of the x-ray spectrum, from which one can infer the ionization state of the sample. In the conditions accessible at the NIF, where the electron temperature is similar to the Fermi energy, the preliminary analysis of the data shows evidence that the carbon atoms have a much higher K-shell ionization. This effect is called ionization potential depression and is still a challenging effect for theory as the most widely used codes fail to predict the NIF measurements.

In his contribution, **Peter Mulser** reviewed the advantage of the x-ray radiation generated by laser-driven plasmas. In his view, plasmas generated by laser-intensities at or above 10^{22} W/vm^2 and the current experimental and theoretical work being done worldwide have many advantages and make a case for a powerful high-intensity laser as follow-on to PHELIX. Effects based on the very strong ponderomotive force generated at this intensity and the fast electrons that result from the laser-plasma interaction must be exploited. In addition, the coupling of the laser energy into the plasma, limited by the reflection of the laser at the critical plasma density, can be mitigated by the use of structured targets that allow the electrons to achieve relativistic velocities (Relativistic Transparency[6]). This technique provides another mechanism for generating high energy density plasmas.

The contribution of **Dimitri Khaghani** dealt with X-ray imaging that finds a wide range of application for the plasma physics beamline at FAIR. From a machine stand-point, spatially resolved Kα and Lyα emission measurement from rest gas in the target chamber will give a precise measurement of the high-energy ion beam used for the HEDatFAIR collaboration. Bent crystals will image the target chamber center outside the target chamber through a thin window onto a CCD and significant signals are expected for ion intensities above 4×10^{10} ions/pulse with a spatial resolution of 100 μm. A second application of x-ray spectrometers is XANES that can be employed at FAIR and also at HHT in the phase-0 for thin low-Z targets heated by the ion beam. Equally important will be the use of such detector in the keV energy range for opacity measurements of warm dense matter. In these last cases, the detector relies on a broadband source of photons that could be provided by a 100 J sub-nanosecond laser, as it is planned for the modular start version of FAIR.

In plasmas generated at the NIF, many by-products of nuclear reactions can be collected after the compression and burn phase of the NIF capsules is over. This post-mortem analysis of the debris, particle and gaseous nuclear by-products provide indirect measurement on processes happening in HED plasmas, as described by **Dieter Schneider** in his contribution. For instance, neutron time of flight measurement after the implosion of a NIF target enables linking the neutron energy to the energy loss of alpha particles in the highly compressed plasma [7]. More advanced concepts exist that employ boron as a dopant in the capsule and detect the products of the ^{10}B(p,a) ^{7}Be reaction where the Be yield directly depends on the plasma temperature. In addition to ignition study relevant measurements, the NIF can be used for more basic nuclear physics process relevant to astrophysics [8]. These studies are relatively new and still in the conceptual and early realization phase, for which detectors are being developed and commissioned. The first results are very encouraging.

3.4 Nanosecond Plasma

Many HED physics experiments are dominated by shock waves driven by transient pressure pulses. The shock pressure ps(t) roughly follows the driving pressure during the growth phase but it reduces slowly when the pressure drops suddenly on the piston. In ideal media the process is known as “hydrodynamic SW attenuation”. Many models

[6] Relativistic Transparency reference

[7] D. Sayre et al., APS Division of Plasma Physics Meeting 2015

[8] D. L. Bleuel et al., Plasma and Fusion Research **11** 3401075, 2016

do not provide the piston acceleration, which is of interest to study the early stage of the Rayleigh-Taylor instability, when a shock driven by a transient pressure is still running inside the slab and the interface acceleration is determined by the shock propagation. The group around **Roberto Piriz** has developed a relatively simple description of the hydrodynamic attenuation (growth and decay) of shock waves which can be obtained from the approximate integration of the conservation equations, and by introducing the "retarded" driving pressure as the boundary condition on the piston. The model serves to several purposes:

- It allows for studying the Rayleigh-Taylor instability (RTI) at the early phase of evolution when the shock is still running into the medium. This phase takes place immediately after the Ritchmyer-Meshkov instability stage, and before the accelerated plate can move as a whole.
- It can also be used for studying the entropy shaping generated by a decaying shock in the ablator layer of an ICF target. This is at present a current method for mitigating the RTI in the ablation front.
- It can be easily extended to convergent spherical and cylindrical geometries for applications to shock waves generated in capsule and liner implosions.

Yongtao Zhao from the Xi'an Jiaontong University in China presented some results covering the energy deposition and wakefield excitation in case an ion beam passes through a plasma target. Effect of the projectile's initial kinetic energy, initial charge state, and nuclear charge Z for low energy ions were investigated. An enhanced energy loss has been observed in case of low energy (100 keV/u) ion beams interacting with hydrogen plasma generated in a discharging pinch. For proton projectiles, the experimental results fit well with the theoretical predictions. For Helium however, the theoretical calculations obviously overestimate the energy loss. Further on wakefield self-modulation for proton beam passing a plasma was observed in experiments. Likewise strong focusing was observed while the energy of the focused beams is uniform. The PIC simulation therefore suggests that the wake-field could form a self-modulated, periodic (pulsed), focusing, collision-less tunnel.

4 Proton microscopy, PRIOR, and the round table discussion

Proton microscopy, the use of temporally-tailored proton beams and magneto-optics to image the properties and behaviour of materials under shocked or extreme conditions, is an important capability for FAIR experimental research. The PRIOR proton microscope is one of the main tools that will be available at FAIR for HED research. In the last years, a prototype of PRIOR, PRIOR I, based on permanent magnets, has been fielded at the high-energy cave of GSI HHT. There, it demonstrated a spatial resolution of 30 μm, in line with predictions, but an unexpected ageing of the permanent magnets under the harsh environment of the accelerator makes the use of permanent magnets unpractical. The technical design of PRIOR II, built around electromagnets, has been approved by FAIR and is planned to be operational for both FAIR Phase 0 and FAIR First experiments, as shown in

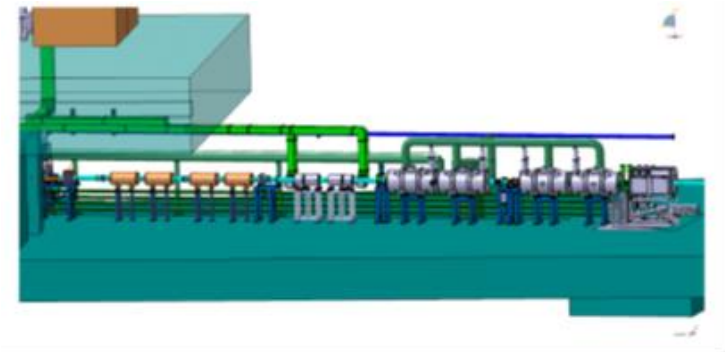

Figure 5: A view of the PRIOR setup at the APPA cave. The PRIOR magnets have a grey support.

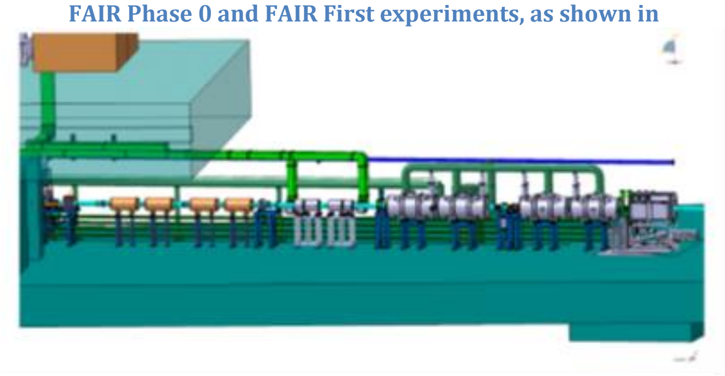

Figure 5. During the workshop, a round-table discussion was facilitated to discuss both the status of PRIOR construction and research applications.

V. Mintsev presented report on the possibilities of the proton radiography for equation of state measurements of shock compressed WDM. The key tasks of special interest for nonideal plasma physics are discussed: Plasma Phase Transition (H2, D2, N2, Noble Gases, etc.), Metal – Insulator Transition, Equation of State – Coulomb interaction, Two Phase Region (Liquid – Gas, including Critical Point), Transport Properties, Optical Properties. Methods of generation of such parameters by powerful shock waves with the aid of high explosives are considered. Compact and full sized explosively driven generators are described from the point of view of their using in the experiments in small "red" GSI chamber (on 150 g of TNT) and in large chamber on 4 kg of TNT, which is now under construction in Chernogolovka. The most attractive looks experiments with strongly coupled plasma of noble gases and plasma phase transitions in H2 and N2. Investigation of Shock Wave Compressibility of Carbon Fiber and Fiberglass for experiments at PRIOR with the help of light gas gun was discussed in the report of **V. Mochalova**.

Frank Merrill's presentation summarized the significant advances in 800 MeV Proton Radiography at Los Alamos over the past several years. Also included was recent research into the potential for Transmission High Energy Electron Radiography. Significant effort at Los Alamos has been dedicated to the development of two models for optimizing 800 MeV Radiography. One model is based on GEANT 4 and allows for the study of impact particles that have scattered substantially or that are generated in the process of interacting with the object and imaging elements. A second model has been developed to study the radiographic performance of lens systems as well as provide a platform for removing the aberrations introduced by the radiography system. Various permanent magnet lens systems have been investigated to improve the radiation resistance of the imaging system including electromagnets.

5 Round table discussion: PHELIX at HHT

During the 2017 EMMI workshop on Plasma Physics at FAIR an open round-table discussion session was held to discuss the scientific opportunities from bringing the PHELIX laser to the existing HHT-cave at GSI. While the session was open to all workshop attendants and GSI scientists, several experts in the field were invited to give their opinion on this proposal and to present ideas and suggestions what scientific areas could be addressed. The attendants were: Prof. Siegfried Glenzer (SLAC), Dr. Thomas Schenkel (LBNL), Prof. David Riley (U. Belfast), Dr. Thomas White (U. Oxford), Dr. Marilena Tomut (GSI, materials research department), Paul Neumayer (GSI, plasma physics department). Though they were not able to attend the discussion in person, further contributions were provided by I. Krasyik, Dr. O. Rosmej (GSI) and Prof. Dominik Kraus (HZDR).

The discussion started with a short presentation by Udo Eisenbarth about the possible optical layout used to transport the beam over to the HHT cave, as shown in Figure 6. The layout is based on the previous project drawings that were made in 2006 with the significant change in requirements that the pulse should be only using the long-pulse (nanosecond) front end and can probably work with a reduced diameter in the APPA cave to save on space and cost. An interesting option that balances costs and performance is to limit the beam size to 150 mm in diameter while enabling an energy of 200 J at 2ω in sub-nanosecond pulses.

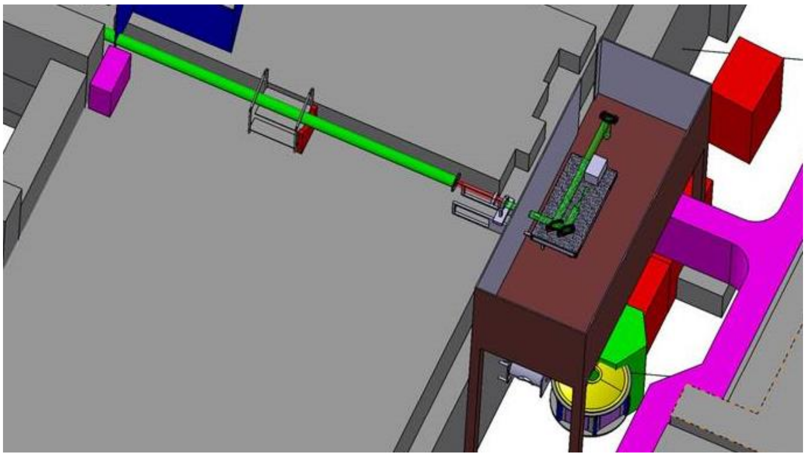

Figure 6: a view of the planned laser beamline (in green) on top of the FRS section of the ESR hall and the laser laboratory container located on top of the HHT cave.

Following this, a round table with short presentations showed the interest of the various participants. This gives a glimpse that these capabilities would raise interest in the community, attract external groups, strengthen and enlarge the FAIR collaboration. These contributions are summarized below:

M. Tomut reported on the need for novel materials and compounds to withstand high strain rates and thermal loads in high-radiation environments, to be used for components such as production targets, collimators or beam dumps at future high-power accelerators (such as the FCC) or as first wall materials in fusion reactors. Modeling of material strength is usually based on known material properties near room temperature, low strain rates and without the simultaneous presence of high radiation fluxes. Therefore, reliably predicting a material's performance requires testing under similar conditions. Such experiments can be conducted at the HighRadMat facilities at CERN, however, the attainable energy deposition and strain rates are quite limited as only proton beams are available. Using uranium ions at HHT will allow significantly higher temperatures and strain rates, even in low-Z targets such as carbon with its many exotic novel forms (e.g. highly-oriented pyrolytic graphite, glassy carbon etc.). In contrast to a post-shot analysis, imaging with laser driven x-rays would enable an in-situ observation of the various hydrodynamic phenomena, such as cylindrical or reflected shock waves, explosion and spallation events, hydrodynamic tunneling, evaporation and plasma generation. Furthermore, x-ray diffraction would give access to microscopic properties such as changes in lattice constant, structural changes and melting.

The contribution provided by **D. Kraus** presented an example experimental setup of a carbon sample being heated by the heavy-ion beam, and using a high-energy laser produced x-ray source as a probe. X-ray diffraction and scattering will provide information on the ionic structure. Such experiments had already been conducted very successfully using laser-shocked samples at the Z6 target area by Kraus et al., revealing the complex structure of dense liquid carbon. Near-isochoric heavy-ion heating of graphite samples with different initial densities will allow reaching new and unexplored parameter regimes. Another idea proposed is to used carbon samples doped with high-Z elements. These will feature absorption edges and laser-driven x-ray sources will enable x-ray absorption spectroscopy for dense matter diagnostic techniques such as XANES and EXAFS.

Similar experiments had been proposed **D. Gericke** (not present) and **P. Neumayer**, studying rapidly heated graphite and diamond samples using x-ray diffraction. Graphite is expected to expand and melt first along the sp2-planes, which would be readily seen in the lattice parameter and diffraction strength across the planes. Diamond on the other hand will undergo graphitization. It is long known that at temperatures of several thousand degrees diamond will turn into graphite within several hours, while recent ultra-fast experiments using x-ray laser pulses showed non-thermal phase transition on the 100 fs time-scale. The experiments at GSI would access the wide parameter space in between and show transformation of diamond to highly compressed graphite on ns-timescales. Another experiment proposed addresses the topic of ionization potential depression (IPD) in strongly-coupled plasmas. This topic has recently gained increased attention due to several experiments at new facilities (LCLS, Orion, AWE), indicating that the widely used standard models for IPD fail, and new theoretical approaches are required in the strongly-coupled regime. At GSI large homogenous samples of strongly-coupled partly degenerate plasmas can be produced in a well-controlled manner and at LTE conditions – ideal for benchmarking of dense matter models – by heavy-ion heating and expansion. An intense broadband x-ray source, produced from a laser-generated high-Z plasma, would be used to perform absorption spectroscopy, probing the electronic excitation spectrum, and thus the continuum edge and the available bound states of such samples.

T. White showed results from recent experiments at the Titan (LLNL) and PHELIX laser facilities. In these experiments, carbon samples were rapidly (ps-timescale) heated by laser-generated protons or supra-thermal electrons. A second laser pulse was used to generate an intense short x-ray pulse used to probe the target, and heating of the ion lattice could be inferred from the intensity reduction of the x-ray diffraction rings. The experiments demonstrate the suitability of high-energy lasers to generate narrow-band x-ray sources sufficiently intense to yield high-quality x-ray diffraction data from short-lived samples like those produced by heavy-ion heating at HHT. This provides valuable diagnostic information such as the lattice temperature below melting, the inter-ionic potential and lattice strength in high-temperature solids through the Debye-Waller factor, and a direct diagnostic signature for melting.

Another experiment proposed by **T. White** addresses the role of radiation damage and dislocation kinetics on elastic precursor decay in materials under shock-loading, of importance for the development of physically-based strength models. In such an experiment, the heavy-ion beam would be used to induce strong radiation damage in a sample, while it is being subjected to a strong laser-driven shock. Performing rear-side velocity measurements with a VISAR system will then yield the elastic-plastic response and material strength parameters of the sample.

S. Glenzer reported on the efforts at SLAC to study transformation of materials under extreme conditions. Employing laser-accelerated proton pulses to damage materials and the ultra-fast x-ray free electron laser LCLS to visualize the transformation on atomic scales via x-ray diffraction and scattering techniques. While ultra-short proton pulses can access the primary defect production as well as highly transient phenomena, they are strongly limited in the attainable projectile energy and charge. Here the high-energy heavy-ions from the GSI accelerator complement and significantly widen the range of possible radiation damage studies, which is also the reason why radiation biology groups and space agencies are strongly interested in experiments at FAIR. Although ultrafast time-scales cannot be accessed due to the 100 ns duration of the heavy-ion pulse, it was pointed out that a large spectrum of secondary processes (e.g. H/He-generation, diffusion and trapping, defect clustering, cascade ageing,…) in the damage cascade happen on time-scales of sub-microseconds to milliseconds. Studying these processes in-situ will require the intense x-ray sources generated by a high-energy laser.

D. Riley emphasized that x-ray scattering is the key diagnostic technique to probe static and dynamic structure of warm-dense matter. He recalled that nanosecond laser driven plasmas can reach of order 10^{-3} conversion of laser energy to x-ray line radiation, and his group is in fact the first to demonstrate elastic x-ray scattering on shock-compressed samples using such laser-driven x-ray sources. Currently his group is involved in establishing this technique on the latest generation x-ray free-electron laser LCLS.

The value for dense matter theory of direct structure factor measurements was also stressed by **C. Meister** (audience). As was also pointed out by **D. Riley** and **S. Glenzer**, who had pioneered ion structure factor measurements on laser-generated warm-dense plasmas using x-ray scattering, these measurements directly probe the ion structure which allows for direct comparison with state-of-the-art dense matter modeling.

O. Rosmej and **I. Krasyik** reported on experiments performed at the Z6 target area utilizing the PHELIX long pulse beam at energies up to 150 J to drive laser-driven shocks into mm-thick aluminum plates in order to induce spallation on the rear side. An electro-acoustical probe was used to measure the time-of-flight of the spallation fragments, and thereby infer their velocity. In addition, the samples were analyzed "post-mortem" by microscopy to measure e.g. crater size and depth. This yields information on the mechanism of destruction of condensed matter at high tensile loads and receive information about of the matter microstructure and density distribution in dynamical stress caused by the laser shock. Performing such spallation experiments using the PHELIX laser beam at HHT would allow conducting in-situ imaging of the spallation event using the proton microscope PRIOR. The expected parameters of PRIOR in terms of temporal and spatial resolution should be ideally suited to the time and spatial scales involved in these scenarios.

T. Schenkel reiterated the high interest in radiation damage studies as presented by T. White and S. Glenzer. More general, he stated the strong added potential and synergetic possibilities of complementing the heavy-ion heated warm-dense matter samples with a powerful x-ray backlighter (for radiography, diffraction, absorption, scattering techniques), or providing an interesting driver for dynamic studies with the proton microscope PRIOR. Given the scientific potential and uniqueness of the combination of intense heavy-ion pulses with a high-energy laser, and in the context of other emerging facilities (XFEL, LCLS-II, Bella), T. Schenkel stressed that there is a clear window of opportunity if such a project were realized within the next three years. It would give first access to discovery science experiments. At the same time it would allow many of the diagnostic concepts and techniques to be developed and tested which will be required for the day-1 experiments when the FAIR facility will go into operation. And finally it could play a crucial role in the community development towards first experiments at FAIR.

There was overall consensus among the participants that having combined laser-ion capability at HHT would provide a unique experimental setup which would significantly enhance the width of the plasma physics program at GSI by attracting new users and community fostering.

6 APPENDIX 1 - List of Posters

Poster session: Monday, July 11th, 2016, 15:30 – 16:50

Id	Title	Presenter
5	Effects of the finite thickness on the Rayleigh-Taylor instability in elastic solid slabs	Ms. PIRIZ, Sofia A.
6	Evidence of Strong Damping in Raman Amplification: Comparison between Simulations and Experiment	FARMER, John
13	Spectroscopic studies of the parameters of plasma jets during their propagation in the background plasma on the PF-3 facility	Dr. ANANYEV, Sergey
14	Harmonic Generation In Magnetized Quantum Plasma with Separate Spin-up and Spin-down Evolution of Degenerated Electrons	Dr. KUMAR, Punit
19	Radiation-hydrodynamic simulations of backlighter options for FAIR	Dr. FAIK, Steffen
20	Model of swift heavy ion tracks excitation	VOLKOV, Alexander
21	A light-gas driver for studies on material properties with PRIOR	ENDRES, Michael
24	Line-imaging VISAR System for Laser-Driven Experiments	Dr. GUBSKIY, Konstantin
25	Ultra-high energy density physics in aligned nanowire arrays	Mr. KAYMAK, Vural
26	Stability of nano and microdiamonds to the action of heavy ions. Thermophysical properties of micro and nanodiamonds at the heating	Ms. ZAKATILOVA, Ekaterina
27	Volume laser destruction in the silica	Dr. EFREMOV, Vladimir
34	High-energy proton microscopy at INR proton linac (proposal)	Dr. KANTSYREV, Alexey
36	Laser-induced ablation plasma: time and space-resolved spectroscopy. Applications	Prof. GURLUI, Silviu
38	Raman amplification in the coherent-wavebreaking regime	FARMER, John
39	Ion acceleration using a flattop laser beam	AFSHARI, Masoud
41	Numerical simulation of proton-radiographic facilities at Geant4	Mr. SKOBLIAKOV, Aleksei
42	Investigation of Shock Wave Properties of Porous Materials for Experiments at PRIOR	Mrs. ZUBAREVA, Alla
43	Electron acceleration in the interaction of intense laser pulses with sharp plasma density profile	Dr. PUGACHEV, Leonid
44	Development of a diagnostic for ultra-intense laser plasma experiments based on frequency resolved optical gating	HORNUNG, Johannes
48	Remagnetization of PMQ lenses for PRIOR and PUMA proton microscopes	Mr. PANYUSHKIN, Vsevolod
50	Improved description of ion stopping in moderately coupled and partially degenerate plasma	Dr. RACZKA, Piotr
51	Diagnostical methods for high energy resolution spectroscopy of the target and projectile X-ray- fluorescence	Mr. ZAEHTER, Sero
54	Synchrotron radiation of polarized electron beams in laser wake field acceleration	Ms. PUGACHEVA, Daria
55	Development of metal plate launcher setup for VISAR Doppler velocimeter test and calibration.	Mr. GAVRILIN, Roman
57	Kelvin-Helmholtz instability in viscous warm dense matter	Dr. MEISTER, Claudia-Veronika Meister
71	Collision processes in partially ionized plasmas	Prof. ROEPKE, Gerd
72	Ionization potential depression in plasmas via structure factors	Prof. ROEPKE, Gerd

7 APPENDIX 2 - List of Participants

Dr. AFSHARI, Masoud
Ms. AMENEH, Kargarian
Dr. ANANYEV, Sergey
Prof. ANDREEV, Nikolay
Mrs. AUMÜLLER, Simone
Dr. AZADNIA, Fateme
Dr. BAGNOUD, Vincent
Dr. BATANI, Dimitri
Dr. BLAZEVIC, Abel
BOCK, Rudolf M.
Mr. BOGDANOV, Anton
Dr. BRAEUNING-DEMIAN, Angela
Dr. BRAMBRINK, Erik
Dr. CHENG, Rui
Mr. CISTAKOV, Konstantin
Prof. CSERNAI, Laszlo
Mr. DING, Johannes
Dr. DOEPPNER, Tilo
Dr. EFREMOV, Vladimir
Dr. EISENBARTH, Udo
ENDRES, Michael
Dr. FAIK, Steffen
Dr. FARMER, John
Mr. GAVRILIN, Roman
Dr. GERICKE, Dirk
Prof. GLENZER, Siegfried
Dr. GOLUBEV, Alexander
Dr. GORBUNOV, Sergey
Dr. GUBSKIY, Konstantin
Prof. GURLUI, Silviu
Dr. GÖTTE, Stefan
Dr. GÜNTHER, Marc
Mrs. HAJIZADEH, Kobra
HANTEN, Jan
Prof. HOFFMANN, Dieter HH
Mr. HORNUNG, Johannes
Prof. IOSILEVSKIY, Igor
Prof. JACOBY, Joachim
JAHN, Diana
Dr. JUHA, Libor
Prof. KANG, Wei
Dr. KANTSYREV, Alexey
Mr. KAYMAK, Vural
Dr. KHAGHANI, Dimitri
Ms. KLEINSCHMIDT, Annika
KLUGE, H.-Jürgen
Dr. KORZHIMANOV, Artem
Dr. KRAUS, Dominik
Dr. KUMAR, Punit
Prof. KÜHL, Thomas
Dr. LI, Lu
Prof. LOMONOSOV, Igor
Dr. MAHDAVIGHARAVI, Marjan
Dr. MAJOR, Zsuzsanna
Dr. MEHLHORN, Thomas
Dr. MEISTER, Claudia-Veronika
Dr. MERRILL, Frank
Prof. MINTSEV, Victor
Dr. MOCHALOVA, Valentina
Mr. MOFAKHAMI, Darius
Prof. MULSER, Peter
Dr. NEFF, Stephan
Dr. NEUMAYER, Paul
Mr. OHLAND, Jonas
Dr. ONKELS, Eckehard
Mr. PANYUSHKIN, Vsevolod
Mr. PATRIZIO, Marco
Dr. PETER, Spiller
Prof. PIRIZ, Antonio Roberto
Mrs. PIRIZ, Sofía A.
Mrs. POURALI, Mahdi
Ms. PUGACHEVA, Daria
Dr. PUGACHEV, Leonid
Prof. PUKHOV, Alexander
Dr. RACZKA, Piotr
Prof. REDMER, Ronald
Prof. RILEY, David
Dr. RODRIGUES, Gerard
ROEPKE, Gerd
Dr. ROSMEJ, Olga N.
Prof. ROTH, Markus
Prof. RUHL, Hartmut
Mr. RUIJTER, Marcel
SANDER, Steffen
Prof. SAVEL'EV, Andrey
Mr. SAVIN, Sergey
Mr. SCHANZ, Martin
Mr. SCHANZ, Victor
Dr. SCHENKEL, Thomas
Mr. SCHILLACI, Francesco
Dr. SCHNEIDER, Dieter
Dr. SCHOENBERG, Kurt
Dr. SCHOENLEIN, Andreas
Dr. SCHUMACHER, Dennis
Ms. SCHUSTER, Anja Katharina
SEIBERT, Marco
Ms. SEPTRIANI, Brigitta
Prof. SHARKOV, Boris
Mr. SKOBLIAKOV, Aleksei
Prof. SON, Eduard
Prof. SPIELMANN, Christian
Dr. TAHIR, Naeem
Dr. TAJIK NEZHAD, samira
Dr. TAUSCHWITZ, Anna
TEBARTZ, Alexandra
Prof. THOMA, Markus
Dr. TOMUT, Marilena
TRAUTMANN, Christina
Dr. VARENTSOV, Dmitry
Dr. WEYRICH, Karin
Dr. WHITE, Thomas
Mr. WINKLER, Bjoern
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