Science with high-power lasers at the European XFEL

T.E. Cowan, HZDR

on behalf of the Helmholtz Beamline User Consortium

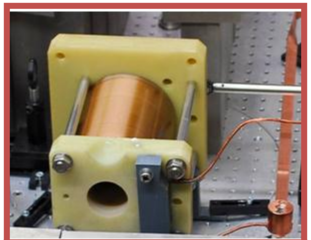
503. WE-Heraeus-Seminar

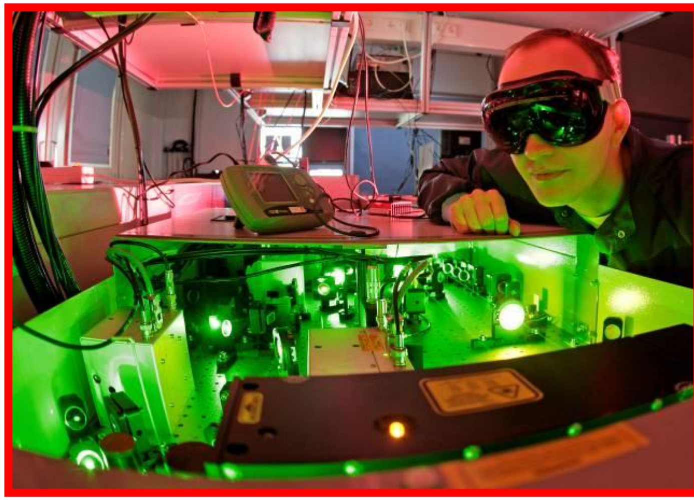
Free-Electron Lasers: from Fundamentals to Applications

10-13. April 2012

Physikzentrum, Bad Honnef

Helmholtz Beamline at the European XFEL



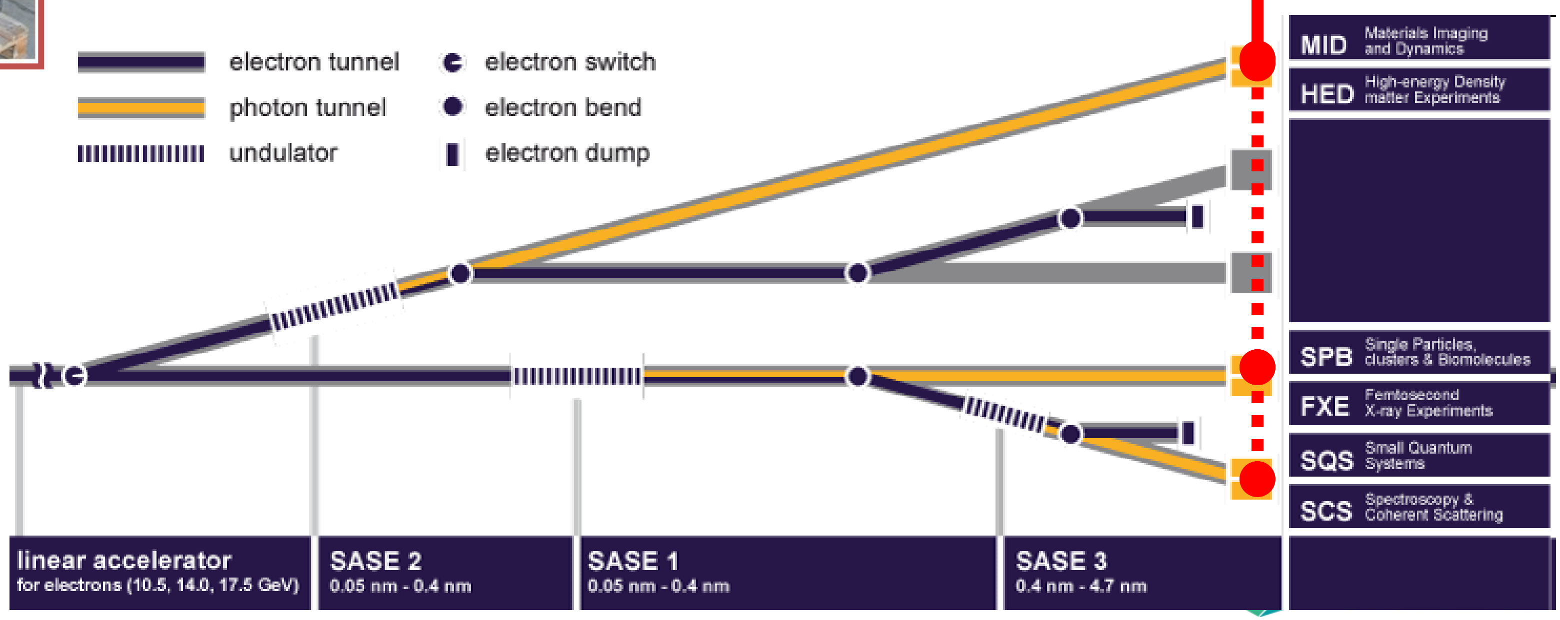


Laser Options (~0.1 – 10 Hz)

~PW, 150J/150 fs DPSSL
~PW, 30 J/30 fs Ti:Saph
~kJ, ~1-10 ns shaped

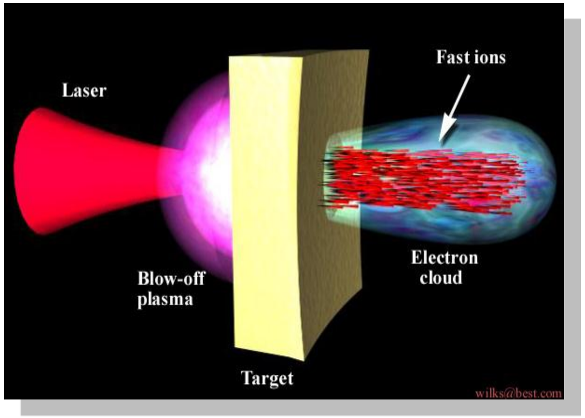
Pulsed Magnets (1 ms, ~50 T)

Optional target chamber for expt. staging

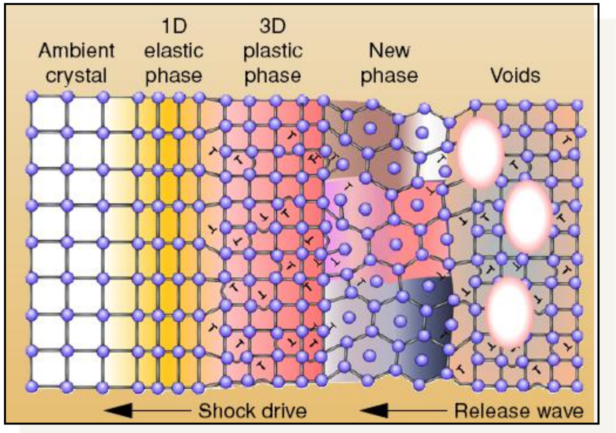


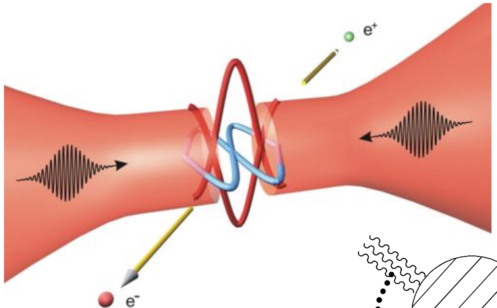
Helmholtz Beamline-XFEL: Ultra-intense & High-energy Lasers

Extreme particle beams

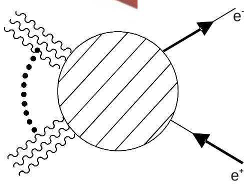


Extreme pressures

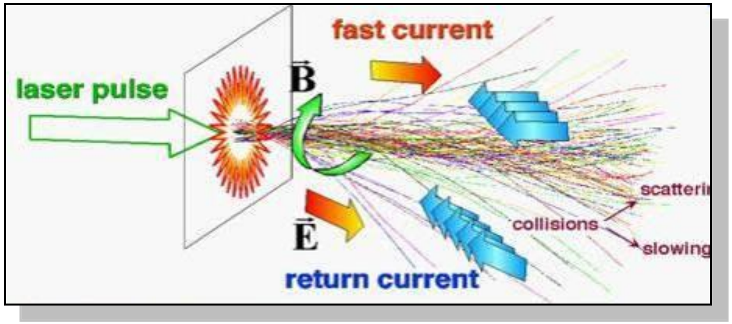


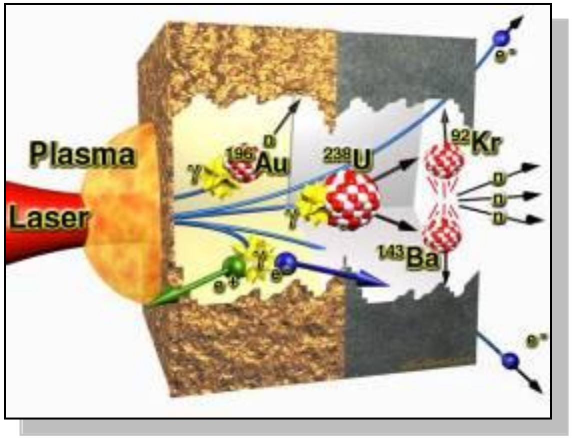


Strong Fields



Extreme currents



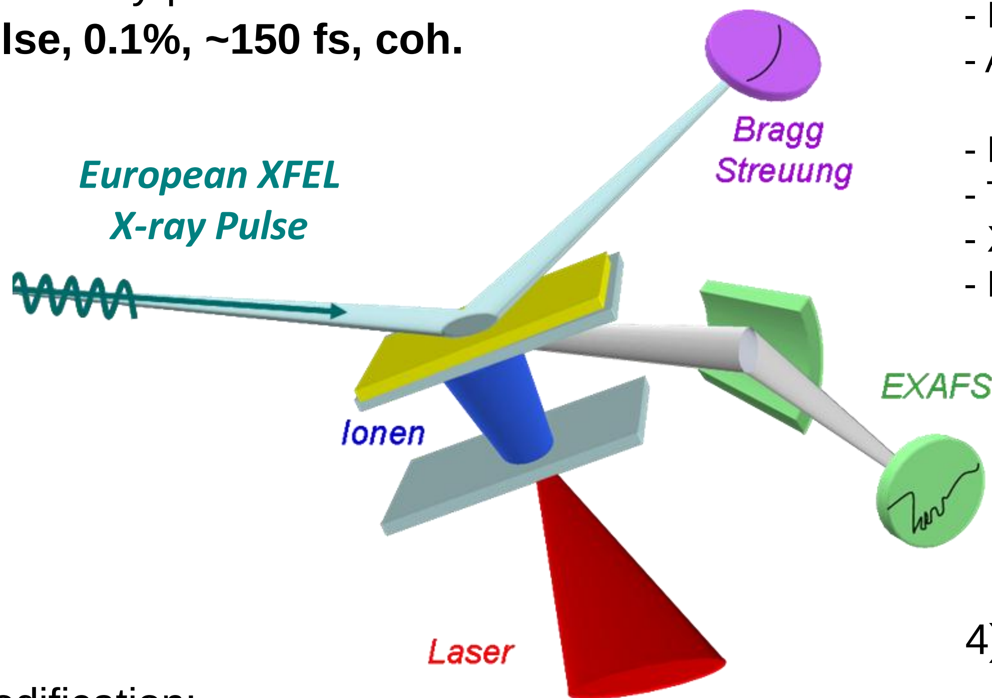


Extreme radiations

Helmholtz Beamline-XFEL: New Experimental Capabilities

1) Synchronized X-ray pulse:
~10^{12} ph/pulse, 0.1%, ~150 fs, coh.

3) XFEL-based probing:
- Bragg & Laue Diffraction
- Absorption Spectroscopy (~10 – 150 fs)
  XAS, XANES, EXAFS
- Radiography, PC Imaging
- Thomson scattering
- XPCS
- Faraday rotation



2) Sample modification:
- Isochoric heating (Laser or XFEL)
- Laser-driven particles & radiation
- Laser-driven shocks
- Ramped cold compression
- w/ or w/o pulsed High-Magnetic field (50 T)

4) Laser-based probing:
- proton radiography
- interferometry, VISAR, FDI
- XUV, X-, γ-ray backlighting
- fs-electron diffraction
- X-ray spectroscopy (~ few ps)
  absorption, self-emission

XFEL-based probing → faster, brighter (focused), coherent

Helmholtz Beamline-XFEL: New Scientific Opportunities

- Extending the scope of HED science at European XFEL
  → extremes of P, T, ρ, j, B- & radiation-fields

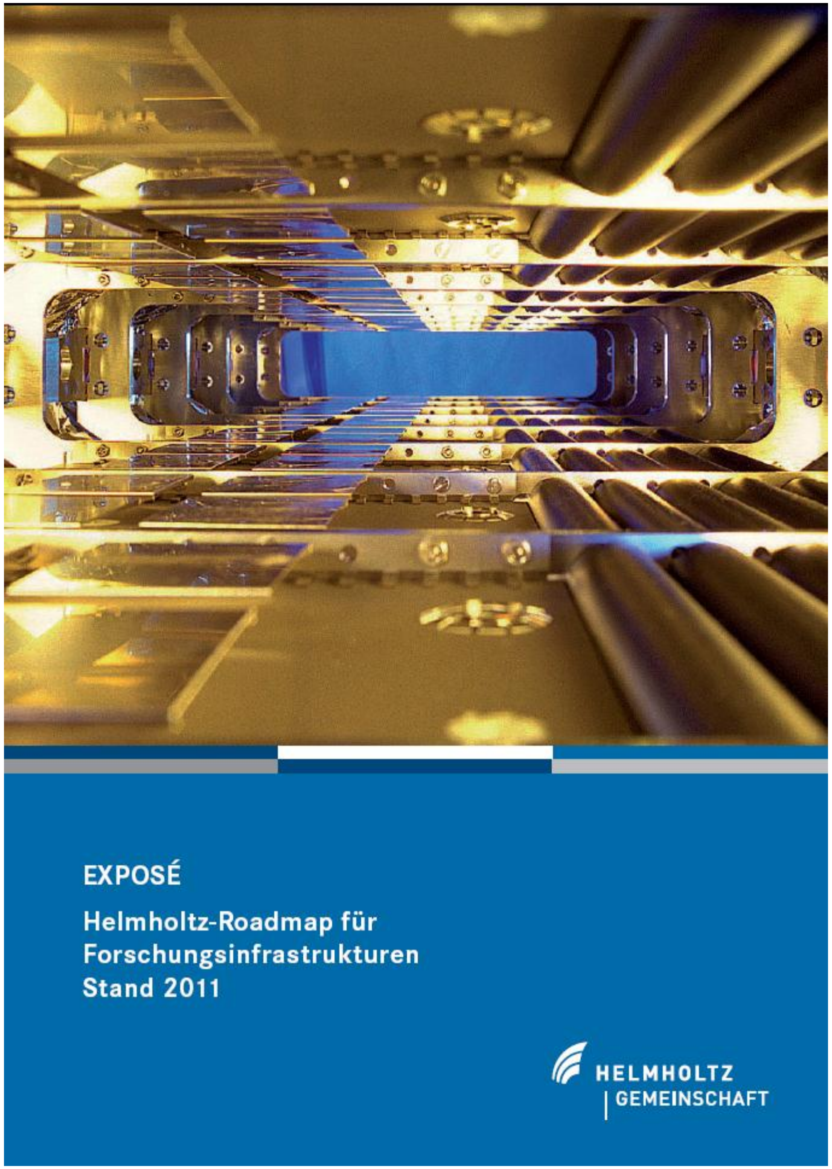
- Exploring new regimes of Strong-field Physics

- Particle- and radiation-driven Dynamic & Non-equilibrium Processes in materials, chemical- and biological-systems

- Fundamental physics of ultra-intense laser-matter interactions for societally-relevant applied research

- Hard x-ray spectroscopy (XMCD, XAS) in magnetic materials and strongly correlated electron systems at high fields (50 T)

Helmholtz Beamline at European XFEL -- Proposed Funding



HELMHOLTZ-BEAMLINE AM EUROPEAN XFEL

Kurzbeschreibung

Das hier vorgestellte Konzept einer Helmholtz-Beamline am Europäischen XFEL basiert auf der Einrichtung einer mit Hochleistungslasersystemen kombinierten XFEL Experimentierstation. Dabei ist geplant, sowohl ein diodenlasergepumptes Kurzpulslasersystem im Petawatt Leistungsbereich als auch ein Hochenergielasersystem einzusetzen. Diese Experimentierstation verfügt damit über eine weltweit einzigartige Kombination aus ultraintensiven Lichtpulsen und hochbrillanten Röntgenpulsen und wird den wissenschaftlichen Einsatzbereich des XFELs deutlich erweitern, da sie das Studium von Materie unter extremen lasergenerierten Temperaturen, Dichten, Drücken und Feldstärken erlaubt. Darüber hinaus bieten sich umgekehrt laserbeschleunigte Teilchenpulse zur Untersuchung von Proben an, die durch den XFEL Puls bestrahlt werden. Diese Forschungsinfrastruktur baut optimal auf der geplanten High-Energy-Density (HED) Experimentierstation des XFEL Basiskonzepts auf, könnte aber bei zusätzlicher internationaler Beteiligung auch als eigenständige Undulatorstrecke eingerichtet werden.

Wissenschaftlicher Hintergrund

Das Studium von Materie bei hoher Energiedichte (HED), die mit den extrem kurzen und brillanten Strahlen des XFEL erzeugt und untersucht wird, stellt eine Säule des wissenschaftlichen Programms des Europäischen XFEL dar, die durch die Helmholtz-Beamline am European XFEL deutlich bereichert wird. Proben werden durch die PW-Laserbestrahlung weit extremeren Drücken, Temperaturen, Feldstärken und Strahlungsflüssen ausgesetzt oder können durch Schockprozesse, die durch die Bestrahlung mit kJ-Laserpulsen ausgelöst werden, in Bereiche hoher Drücke und Energiedichten versetzt werden. Eine besonders interessante Perspektive zur Ergründung fundamental neuer Physik bietet zudem die direkte Messung der Polarisierbarkeit des QED-Vakuums in extrem starken elektromagnetischen Feldern. Diese erfordert die Messung der Drehung der Polarisationsrichtung des XFEL-Röntgenstrahls beim Durchgang durch die extremen Felder im PW-Laserfokus, die auf der induzierten Doppelbrechung des Vakuums beruht.

Nutzenperspektive

Die Forschung an der neuen Helmholtz-Beamline am XFEL wird erheblichen Einfluss auf Untersuchungen von ultraschnellen und Nicht-Gleichgewichts-Prozessen in unterschiedlichen Systemen unter extremen Bedingungen haben. Dazu gehören beispielsweise Studien des Vakuumzustands der QED in starken Feldern; die Bestimmung der Zustandsgleichungen (EOS) warmer dichter Materie für die Geo- und Planetenforschung; die Ermittlung der Eigenschaften heißer Plasmen in Bezug auf ihr Strahlungsverhalten und ihre dynamischen Eigenschaften, die in der stellaren Physik mit Blick auf Supernovae und Gamma-Ray Bursts, aber auch im Rahmen der Fusionsforschung von Interesse sind; die Erforschung ultraschneller Prozesse in strahlungs- sowie partikelinduzierter Schädigungen in Werkstoffen, die bedeutend für das Verständnis bei der Ionenimplantation in Halbleitern oder der Frage der Versprödung von Materialien in Reaktoren oder an Raumfahrzeugen durch kosmischer Strahlung ist; sowie chemische Studien angeregter Zustände, um Risiken der Umweltkontamination zu mindern und vieles mehr.

Daten und Zahlen

Zeitplan:
- Bau: 2015–2018
- Betrieb: 2017–2035

Geschätzte Kosten:
- Baukosten: 40 Mio. € Helmholtz-Gemeinschaft (PW 15 M€, kJ 5 M€, Targetkammer 5 Mio. €, Detektoren 15 Mio. €).
- Betriebskosten: 1 Mio. € p.a.
- Rückbaukosten: noch nicht spezifiziert

Internationale Dimension:
Als weltweit einzigartige Einrichtung wird bei der Helmholtz-Beamline am XFEL eine starke internationale Beteiligung aus Europa (Frankreich: CEA / CNRS, UK: Oxford, Schweiz: PSI, sowie Beiträge aus Russland, Indien und den USA: LANL, LLNL, SLAC) erwartet. Eine weitere internationale Beteiligung von 23 Mio. € wird für einen dediziertes Undulator-und Röntgen-Strahlrohr (13 Mio. € Undulator, 5 Mio. € X-Ray-Beamline, 5 Mio. € Tiefbau) diskutiert.

Rolle des Zentrums/der Zentren:
Die Helmholtz-Beamline am European XFEL wird gemeinsam vom HZDR (PW- und kJ-Lasersysteme) und von DESY (Kammer und Detektoren) entwickelt in wissenschaftlicher Zusammenarbeit mit GSI, HALLO-Jena und IPP. Die technische Konzeption und der Bau wird von der European XFEL GmbH koordiniert.

Weitere Informationen:
www.hzdr.d

Website: www.hzdr.de/hgfbeamline

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Helmholtz-Beamline at European XFEL – User Consortium

Proposal for a X-FEL User Consortium for the
HELMHOLTZ-BEAMLINE at the European XFEL
19. March 2012

The HELMHOLTZ-BEAMLINE at the European XFEL will establish multi-purpose high-power and ultra-intense lasers as well as high-field magnets at the SASE2 end-station of the European XFEL. This will constitute a world-wide unique combination of ultra-high power lasers and high-field magnets with a high-brilliance X-ray source. It will extend the scope of research that can be carried out at the European XFEL beyond the baseline Instruments, especially in the areas of strong-field physics, high energy density science, relativistic laser-plasma physics, ultra high-pressure astro- and planetary-physics, dynamic materials research, and magnetic phenomena in condensed matter. The laser systems will include: an ultra-intense PW-class laser operating with full energy at 1 Hz, and at 200 TW at 10 Hz, based either on emerging diode-pumped solid-state laser technology, or on commercially available Ti:Sapphire technology; a high energy kJ-class laser with few ns-duration shaped pulses for shot-on-demand operation, with a 100 J-class stage operating at 1 Hz; and a 1.5 MJ pulse generator to drive pulsed high-field magnets (50 T, ~1ms) for condensed matter and magnetized HED-plasma research. The HELMHOLTZ-BEAMLINE will be used to drive matter to extremes of temperature, density, pressure, field strength, and/or particle irradiation, which can be probed with the XFEL beams; or alternatively to probe XFEL-driven samples with laser-generated particles or radiation. The HELMHOLTZ-BEAMLINE is being proposed for funding from the Helmholtz Association research area "Matter," by partners HZDR, DESY and HI-Jena. Over 80 research groups from more than 60 institutions in 15 countries have joined this User Consortium as External Partners.

Helmholtz Partners:	T.E. Cowan, U. Schramm (HZDR)
	E. Weckert (DESY)
	Th. Stoehlker (HI Jena)
European XFEL Contact:	Th. Tschentscher

Website: www.hzdr.de/hgfbeamline

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Helmholtz-Beamline at European XFEL – User Consortium

Present partners at German Universities and Research Institutes

Centre for Free-Electron Laser Science, CFEL/DESY
Dr. A. Barty & coworkers

DESY, Hamburg
Prof. E. Weckart & coworkers, (Photon Science and HASYLAB)
Dr. S. Toleikis, Dr. M. Harmand, Dr. S. Dusterer et al (FLASH-WDM Group),
Dr. H.-P. Liermann (Extreme Conditions), Dr. H. Franz (Nucl. Res. Scatt.),
Dr. J. Strempfer, Dr. M. v. Zimmermann (Magnetism and Correlated Electrons)

ExtreMe Matter Institute, EMMI-GSI
Dr. P. Neumayer; Dr. A. Gumberidze

GFZ - Deutsches GeoForschungsZentrum Potsdam
Prof. W. Heinrich & coworkers.

GSI - Darmstadt
Dr. V. Bagnoud, Prof. Th. Kühl, Dr. U. Eisenbarth, Dr. S. Götte, Dr. A. Blazevic,
Dr. A. Tauschwitz, Dr. O. Rosmej, Dr. K. Weyrich, Dr. W. Quint

Helmholtz-Institut Jena (HIJ)
Prof. T. Stoehlker, Dr. G. Weber, Dr. R. Märtin, Dr. E. Förster, Dr. O. Jäckel,
Dr. R. Bödefeld, Dr. B. Zielbauer, Dr. S. Trotsenko, M. Hornung, F. Karbstein

Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
Prof. T. Cowan, Prof. U. Schramm, Prof. B. Kaempfer, Prof. R. Sauerbrey,
Dr. M. Bussmann, Dr. S. Kraft, Dr. M. Siebold et al (Laser Part. Accel)
Dr. K. Fahmy et al (Biophysics Group), Dr. M. Gensch et al (THz Group)
Dr. J. Grenzer, Dr. M. Posselt et al. (Inst. Ion Beam Phys & Mat Res)
Dr. T. Herrmannsdoerfer et al. (High- magnetic-field Lab Dresden, HLD)

Max Born Institute Berlin
Prof. W. Sandner, Prof. M. Schnürer & coworkers

Max-Planck-Institut für Kernphysik
Prof. C.H. Keitel, Dr. A. Palffy, PD Dr. K.Z. Hatsagortsyan, PD Dr. A. Di Piazza

Max-Planck-Institut für Quantenoptik (MPQ)
Dr. Z. Major

OncoRay, Gustav Carus Medizinsches Fakultät, TU Dresden
Prof. N. Cordes, Prof. A. Dubrovsky

Universität Bayreuth
Prof. Dr. L. Dubrovinsky & coworkers (Bayerisches Geoinstitut)

Technische Universität Darmstadt
Prof. M. Roth & coworkers (Institut für Kernphysik)

Technische Universität Dresden
Prof. Dr. C. Schroer & coworkers (Institut für Strukturphysik).

Universität Frankfurt am Main
Prof. B. Winkler & coworkers (Institut für Geowissenschaften)

Albert-Ludwigs-Universität Freiburg
Prof. Th. Kenkmann & coworkers (Institut für Geowissenchaften)

Friedrich-Schiller-Universität Jena
Prof. H. Gies & coworkers (Theor. Physik. Inst.)
Prof. G. Paulus, Prof. M. Kaluza, Dr. I. Uschmann & coworkers (IOQ-Jena)

Ludwig Maximilian-University, Munich (LMU)
Prof. H. Ruhl, Dr. N. Elkina, Dr. C. Klier & coworkers
Prof. S. Karsch & coworkers

Universität Rostock
Prof. Dr. R. Redmer & coworkers

University of Siegen
Prof. Dr. U. Pietsch & coworkers

Present European and other Partners

CH: Paul-Scherrer-Institute
Dr. A. Froideval, Dr. J. Bertsch, Dr. J. Chen, Dr. C. Degueldre, Dr. M. Krack, Dr. G. Kuri,
Dr. M. Martin, Dr. S. Portier, Dr. M. A. Pouchon, Dr. F. Devynck, Dr. I. Lund

CZ: FZU - Insitute of Physics, Academy of Science of Czech Republic
Prof. G. Korn, Prof. J. Krasa, Prof. B. Rus, Dr. D. Margarone & ELI-Beamlines Team

ES: CLPU – Centro de Laseres Pulsados Ultracortos Ultraintensos, Univ. of Salamanca
Prof. L. Roso, Dr. R. Torres & coworkers

FR: IRAMIS, CEA, Saclay
Prof. H. Merdji & coworkers (Service des Photons, Atomes et Molécules)

CEA, Arpajon
Prof. P. Lobeyre & coworkers (High Pressure Group)

LULI, Ecole Polytechnique–CNRS–CEA-UPMC
Dr. P. Audebert, Dr. S. Baton, Dr. J. Fuchs & coworkers (ELFIE group)
Dr. M. Koenig & coworkers (High Energy Density group)

CELIA (Centre Lasers Intense et Applications), Universite Bordeaux
Prof. D. Batani, Dr. F. Dorchies, Dr. J.J. Santos & coworkers
Prof. V. Tikhonchuk, Dr. E. d'Humieres & coworkers

Universite Sorbonne, Universite Pierre et Marie Curie (UPMC)
Prof. F. Rosmej, Dr. P. Angelo, Dr. K. Bennadji & coworkers.

HU: University of Pecs, Institute of Physics
Prof. J. Hebling, Prof. J. A. Fulop

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Helmholtz-Beamline at European XFEL – User Consortium

IT: SAPIENZA Unviersity of Roma
Prof. L. Palumbo, Dr. L. Lancia, Dr. P. Antici

PL: Military University of Technology, Warsaw
Prof. H. Fiedorowicz & coworkers (Institute of Optoelectronics)

RU: Joint Institute for High Temperatures, Russian Academy of Sciences
Dr. S. Pikuz & coworkers

SE: Stockholm University
Prof. U. Häussermann & coworkers

Umea University
Prof. M. Marklund, Dr. A. Ilderton, Dr. Chris Harvey, A. Gonoskov

Uppsala University, Institute of Molecular Biophysics
Prof. J. Hajdu, Dr. J. Andreasson, Dr. N. Timneanu, Dr. M. Svenda, B. Iwan, & coworkers

UK: University of Edinburgh
Prof M. McMahon, Prof. R. Donovan, Dr. C. Murphy & coworkers.

Imperial College (IC)
Prof. S. Bland, Dr. D. Eakins & coworkers

Queens University Belfast (QUB), Centre for Plasma Physics
Prof. M. Borghesi, Prof. C. Lewis, Prof. D. Riley, Prof. M. Zepf, Dr. B. Dromey & coworkers

University College London (UCL)
Prof. P. McMillan, Dr. C. Pickard, Dr. F. Cora, Dr. M. Gillan, & coworkers

University of Oxford
Prof. J. Wark, Prof. G. Gregori & coworkers

University of Plymouth
Prof. T. Heinzl, Prof. D. McMullan, Dr. K. Langfeld, Dr. M. Lavelle, N. Iji, M. Raddadi

Scottish Universities Physics Alliance (SUPA)
Prof. K.D. Ledingham & coworkers (Nuclear Interactions at High Temperatures)

University of Strathclyde
Prof. D. Jaroszynski, Dr. S. Cipiccia, & coworkers

CN: Institute of Physics, Chinese Academy of Sciences (IOP-CAS)
Prof. Yutong Li & coworkers

Peking University (PKU)
Prof. Dr. Xueqing Yan & coworkers (Inst. of Heavy Ion Physics)

Shanghai Jiao Tong University (SJTU)
Prof. Zheng-Ming Sheng & coworkers

Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences
Prof. Ruxin Li & coworkers

IN: Tata Institute of Fundamental Research (TIFR)
Prof. G. Ravindra Kumar & coworkers

JP: Institute of Laser Engineering, ILE – Osaka University
Prof. H. Takabe, Dr. L. Baiotti, Dr. T. Moritaka (Theory)
Prof. Y. Sakawa, Prof. Y. Kuramitsu, Dr. T. Morita (Expt. Lab. Astrophys.)
Prof. A. Hosaka (Research Center for Nuclear Physics).
Prof. K. Mima (Fusion Materials)

Kansai Photon Science Institute (KPSI), JAEA
Prof. P. R. Bolton, and coworkers

Kyoto University, Institute for Chemical Research
Prof. S. Sakabe, & coworkers (Advanced Research Center for Beam Science)

US: Carnegie Institution of Washington
Prof. A. Goncharov & coworkers (Geophysical Laboratory)

General Atomics
Dr. R. Stephens, Dr. M-S Wei & coworkers

Los Alamos National Laboratory
Dr. K. Schoenberg, Dr. J. Sarrao, Dr. C. Barnes, Dr. J. Fernandez, Dr. M. Hegelich & coworkers

Lawrence Berkeley National Laboratory
Prof. R. W. Falcone, Dr. B.-I. Cho.

Lawrence Livermore National Laboratory
Dr. M. Armstrong (High Pressure Group); Dr. G. Collins et al (High Energy Density Section)
Dr. S. H. Glenzer et al (Plasma Physics Group), Dr. S. Hau-Riege et al (X-ray Group);
Dr. P. Patel et al (Fast Ignition-Fusion Energy Sciences Program);
Dr. R. Shepherd, Dr. H. Chen, Dr. R. Cauble et al. (Jupiter Laser Facility)

Oak Ridge National Laboratory, Materials Science and Technology Division
Dr. B. Larson (Senior Fellow), Dr. J. Tischler, Dr. G. Eres, Dr. Y. Osetskiy, Dr. G. Samolyuk,
Dr. R. Stoller, Dr. S. Xu

Ohio State University, Department of Physics
Prof. R. R. Freeman & coworkers (High Energy Density Physics group)

The Rockefeller University
Prof. T. P. Sakmar, M.D.

SLAC National Accelerator Laboratory
Dr. R. Nagler, & coworkers (LCLS-MEC)

University of California, San Diego
Prof. F. Beg & coworkers (Dept. Mechanical & Aerospace Eng.)

University of Nevada, Reno
Prof. Y. Sentoku

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Helmholtz-Beamline at European XFEL – Institutions & Topics

Germany: 20
CFEL, DESY, EMMI-GSI, GFZ-Potsdam, GSI, HI-Jena, HZDR, MBI, MPIK-HD, MPQ, OncoRay, Uni Bayreuth, TU Darmstadt, TU Dresden, Uni's Frankfurt, Freiburg, IOQ-Jena, LMU-Munich, Rostock, Siegen

Europe: 24
PSI (CH); FZU-PALS (CZ); CLPU-Salamanca (ES); IRAMIS-CEA, CEA-Arpajon, LULI, CELIA-Bordeaux, UPMC (FR); Univ Pecs (HU); Uni Roma (IT); MUT-Warsaw (PL); JIHT-RAS (RU); Stockholm, Umea, Uppsala (SE); Edinburgh, IC, QUB, UCL, Oxford, Plymouth, SUPA, Strathclyde (UK); European XFEL

Asia: 8
IOP-CAS, Peking Univ., Univ. Shanghai, SIOM (CN); Tata IFR (IN); ILE-Osaka, JAEA-Kansai, Univ. Kyoto (JP);

US: 11
Carnegie Inst. Wash., General Atomics, LANL, LBNL, LLNL, ORNL, Ohio State, Rockefeller Univ, SLAC-LCLS, UCSD, UNR

		Nr	%	%
DE	HGF	74	10.9	33.3
	DE	152	22.4	
EU	UK	73	10.8	33.9
	FR	39	5.8	
	ES	29	4.3	
	SE	28	4.1	
	CH	10	1.5	
	CZ	10	1.5	
	PL	10	1.5	
	RU	10	1.5	
	HU	9	1.3	
	IT	6	0.9	
	XFEL	6	0.9	
Asia	CN	94	13.9	17.8
	JP	22	3.2	
	IN	5	0.7	
US	US	101	14.9	14.9

>85 Groups, 63 Institutions, ~360 faculty/scientists, ~300 students

	Structural dynamics – Materials / Bio	21 groups
	Relativistic Laser Matter Interaction	32 groups
	Magnetic Materials* (recent)	2 groups
	High Pressure Physics	16 groups
	Strong field & nuclear physics	16 groups
	Warm dense matter	26 groups

Faculty/Groups	86
Institutions	63
Faculty/Staff/Students	678

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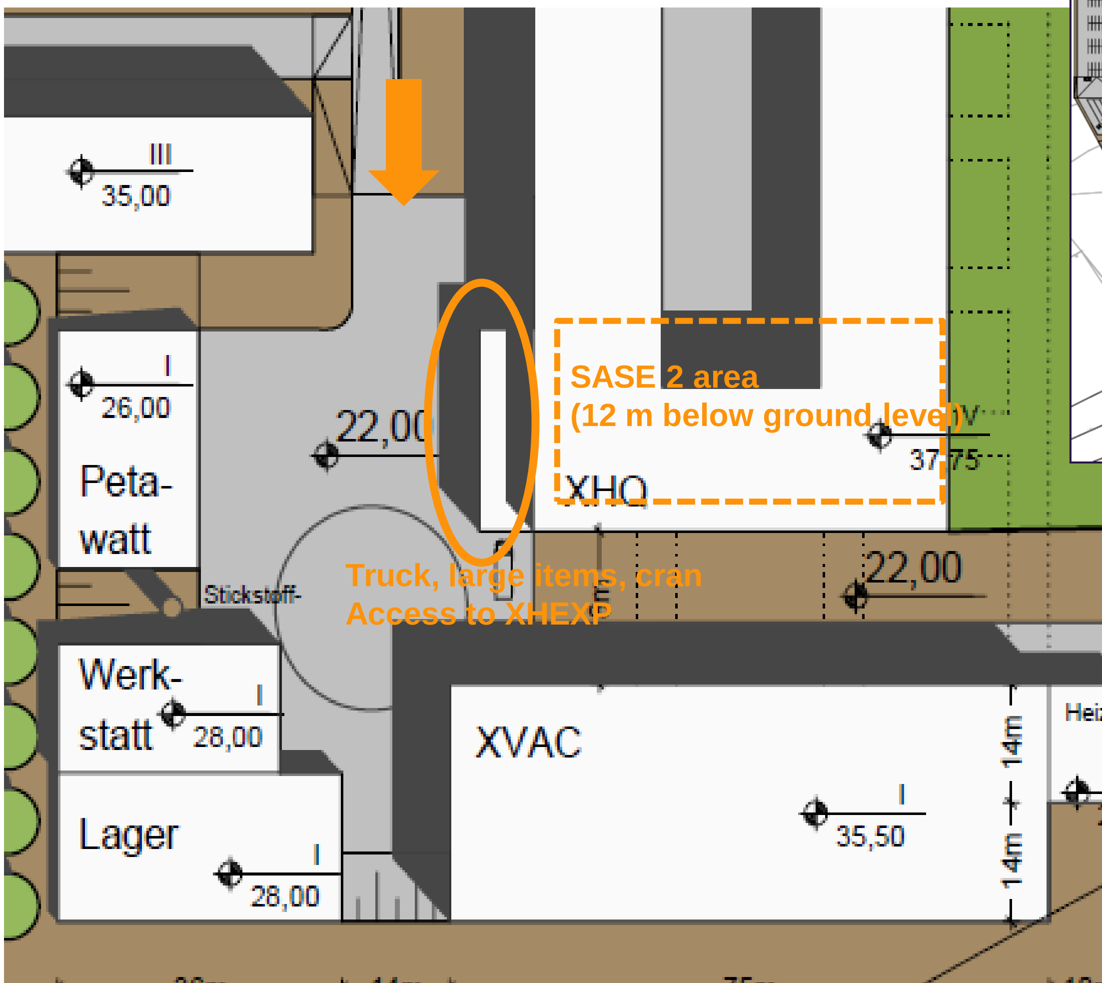
Helmholtz-Beamline at European XFEL – Partner Contributions

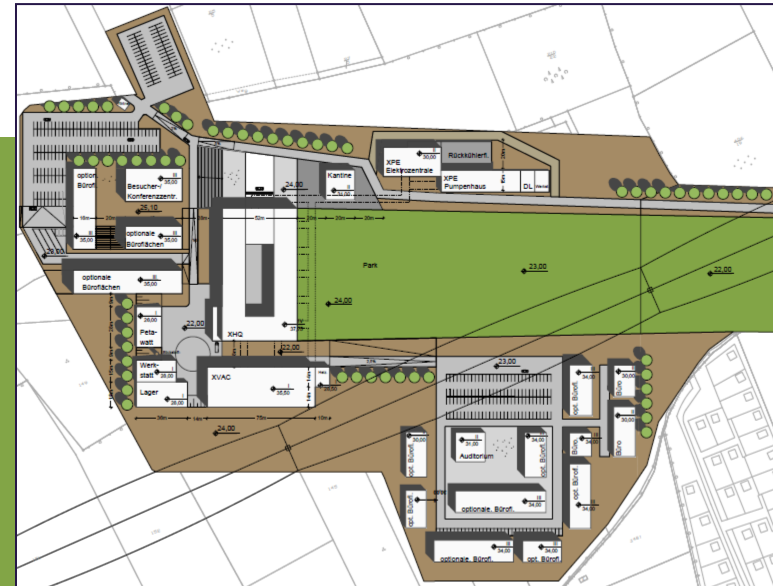
CIW (Goncharov et al): Single-shot broadband optical, and Coherent Anti-Stokes Raman spectroscopy.
CELIA (Batani, Dorchies et al): Hot plasma and High Pressure diagnostics & expertise.
CLPU-Salamanca (Roso et al): UHV chamber and metrology; short-pulse laser expertise.
DESY (von Zimmerman et al): Beamline and high-magnetic field experiment infrastructure.
FZU-Prague (Korn et al): Laser-plasma diagnostics.
General Atomics (Stephens et al.): Target insertion technology; advanced target fabrication.
GFZ-Potsdam (Heinrich et al): X-ray scattering system (DAC), X-ray spectroscopy system (DAC).
IOP-CAS (Li et al): X-ray and spectrometers, electron & ion spectrometers; diagnostics; targets.
IOQ-Jena (Paulus, Uschmann et al): Channel-cut crystal hard x-ray polarimeters.
JIRT-RAS (Pikuz et al): crystal-based x-ray spectrometers with high spectral and spatial resolution; X-ray backlighting and X-ray microscopy components; crystal-based X-ray detectors.
KPSI (Bolton et al): Particle spectrometry, fast particle beam diagnostics; ultra-fast X-ray diagnostics.
Kyoto Univ. (Sakabe et al): Ultrafast electron diffraction system.
LBNL (Falcone et al): Spectrometer for inelastic x-ray scattering.
LLNL (Armstrong et al): High rep-rate 0.1 mJ high-pressure experiment capability using XFEL PP Laser.
LLNL (Hau-Reige et al): Contributions to X-ray Thomson scattering instrumentation and analysis.
LLNL (Shepherd et al): sub-ps X-ray Streak Camera.
LULI (Koenig et al): VISAR diagnostic. SOP diagnostic.
MBI-Berlin (Sandner et al): EUV spectrometer, Ion spectrometer, X-ray spectrometer.
MUT-Warsaw (Fiedorowicz et al): X-ray imaging system; high-energy laser system developments.
OSU (Freeman et al.): Compact Thomson parabolas for ions (pos. & neg.), positrons, & electrons.
Oxford Univ. (Wark/Gregori): Instrumentation for X-ray Thomson scattering and Spectroscopy.
SIOM (Li et al): Space- and time-resolved XUV spectrometer, high-resolution electron spectrometer.
SJTU (Sheng et al): X-ray spectrometers; THz spectrometers; Electron/Ion detectors; novel Targets.
Tata IFR (Kumar et al): Ultrafast dynamics and polarization measurement.
TU-Darmstadt (Roth et al): X-ray diagnostics; advanced laser targets; cryogenic laser targets.
TU-Dresden (Schroer et al): X-ray microscope; X-ray nano-focus system.
Univ. Bayreuth (Dubrovinsky et al): DAC's; internal laser heater (DAC); external E-field Pulser (DAC).
UC San Diego (Beg et al): Bremsstrahlung spectrometer; 2D Kα imager; HOPG spectrometer.
Univ. Frankfurt (Winkler et al): time-resolved laser fluorescence spectroscopy.
Univ. Pecs (Hebling et al): laser-based 1 mJ THz source.
Univ. Roma (Palumbo et al): Laser-proton diagnostics with associated data processing.
Univ. Siegen (Pietsch et al): Apparatus to apply high external electric fields to samples.
Univ. Stockholm (Haussermann et al): High-pressure experiment instrumentation.
Univ. Uppsala (Hajdu, Andreasson, et al): Sample injection system & related diagnostics.

Partial List, 15.03.12

European XFEL

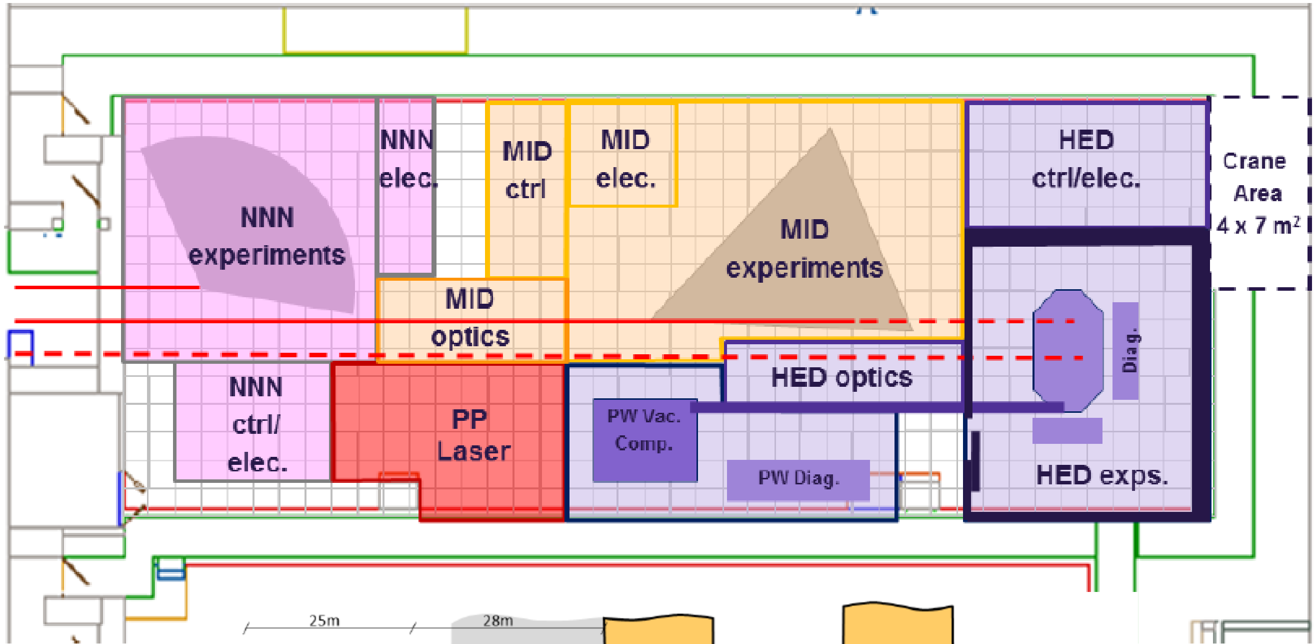
Surface building near SASE 2

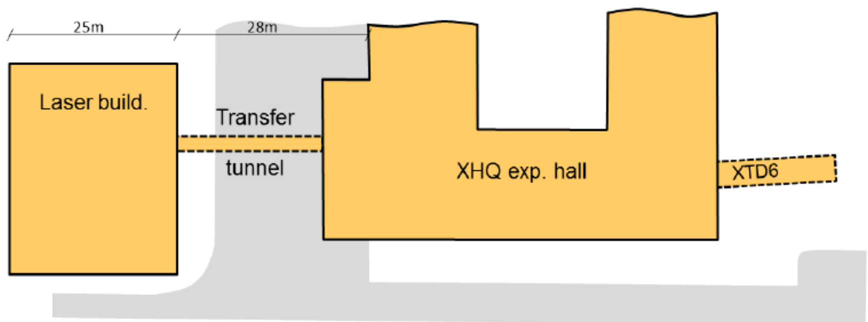


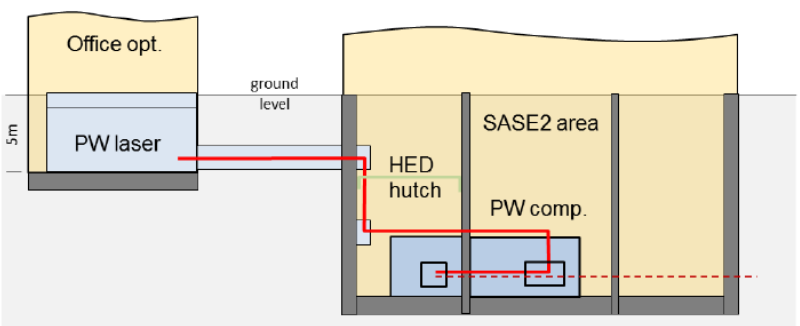


Helmholtz Beamline-XFEL

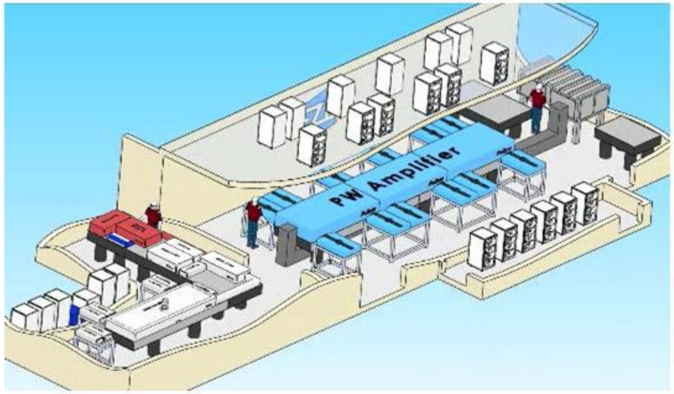
SASE2

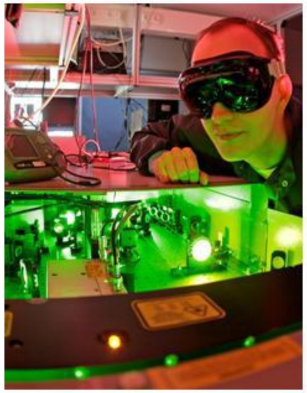




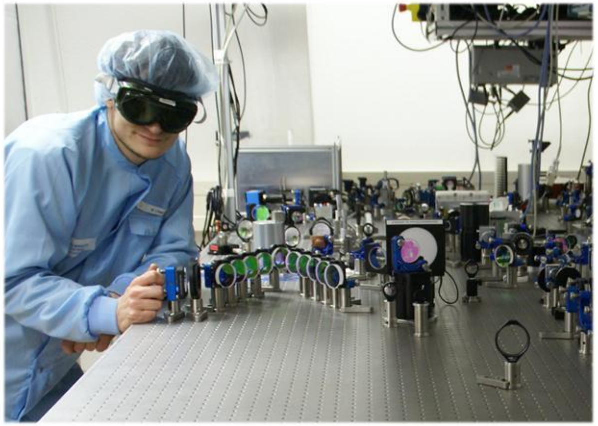


Helmholtz Beamline-XFEL: PW Laser Options

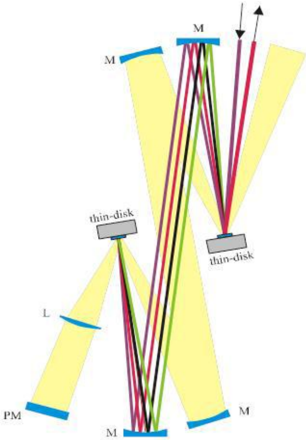


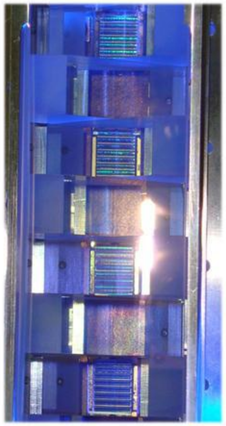


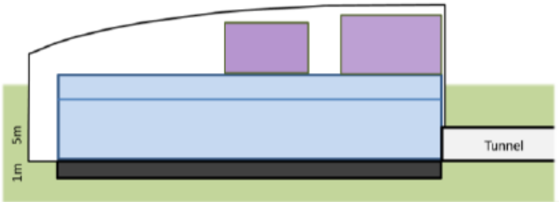
Ti:Sapph
30 J / 30 fs / 1 Hz
6 J / 30 fs / 10 Hz



Diode-pumped CaF2
200 J / 150 fs / 1 Hz







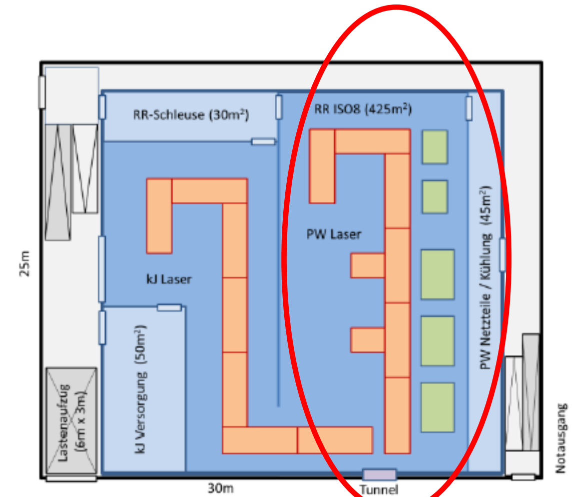
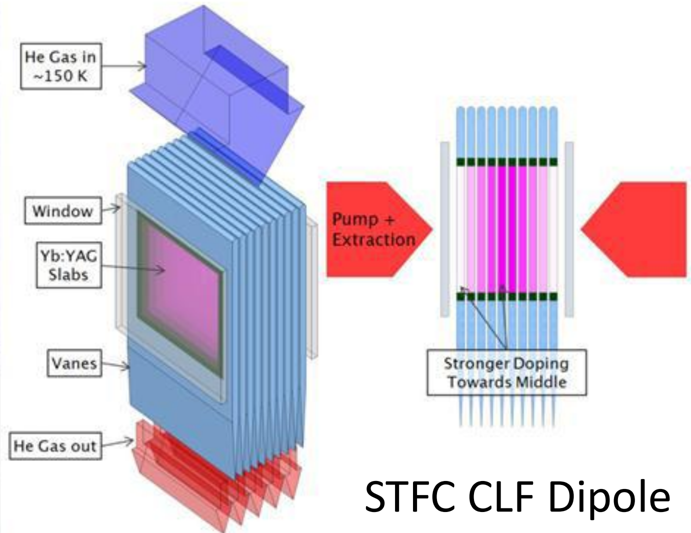


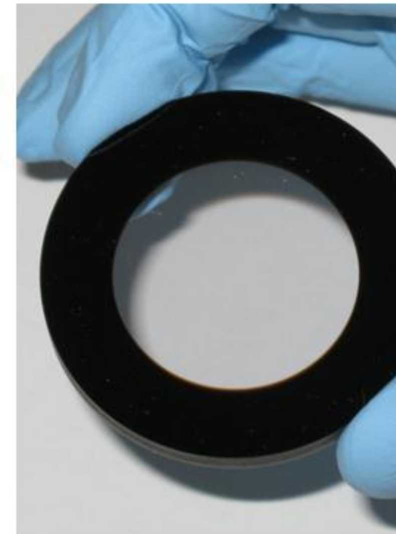
Fig. 9: Side view of the underground levels of the proposed laser building which does not yet incorporate additional office space in potential upper floors (left). Foot-print of the clean-room laser lab showing examples of PW and kJ laser table installations (right).

Helmholtz Beamline-XFEL: kJ-class Laser Options

Diode-pumped Mercury (LLNL)
60 J / 10 Hz



STFC CLF Dipole
10 J / 10 Hz



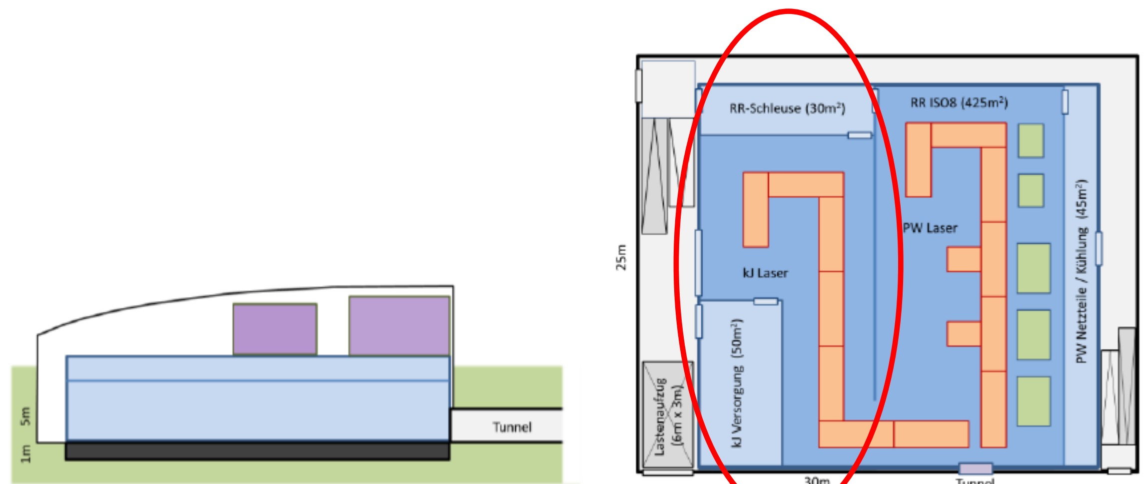
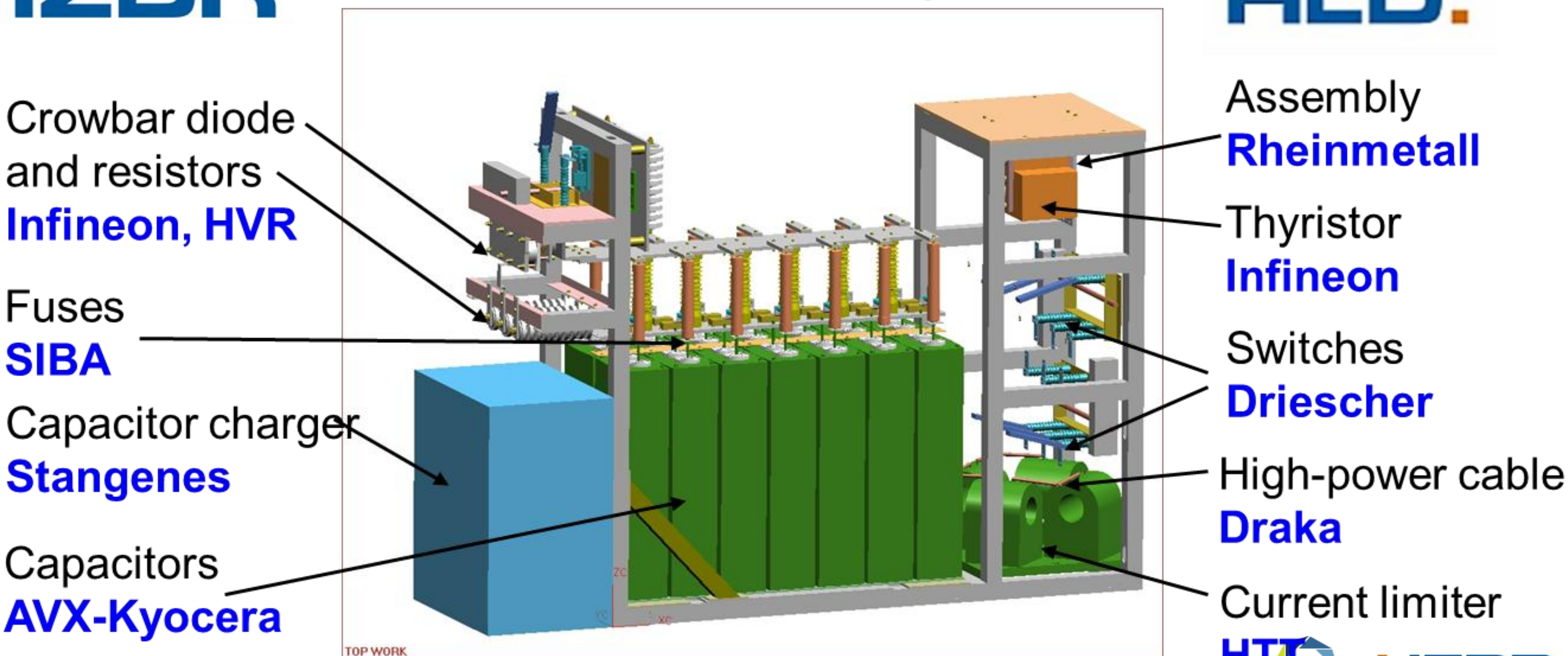


Fig. 9: Side view of the underground levels of the proposed laser building which does not yet incorporate additional office space in potential upper floors (left). Foot-print of the clean-room laser lab showing examples of PW and kJ laser table installations (right).

High fields for science

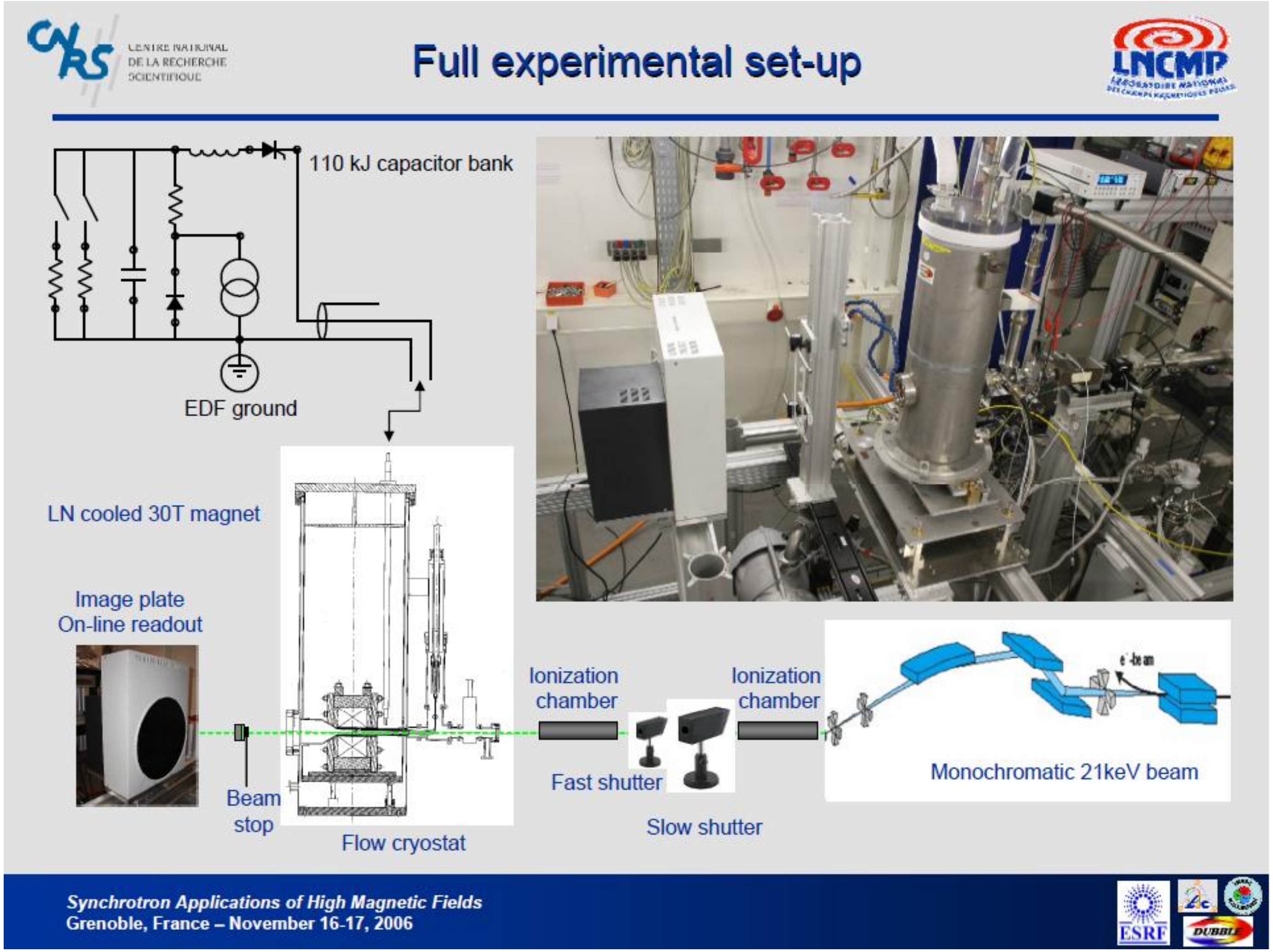
Module design of the
50 MJ capacitor bank of the HLD

HZDR **1,44 MJ / 24 kV / 40 kA – Pulsed-power module** HLD.



DRESDEN concept HZDR

Helmholtz Beamline-XFEL: X-ray Magnetic Absorption & Scattering



- Full magnetic field history (XMCD, XAS) in single macropulse train
- Allows much higher fields (50 T), versus at ESRF

Helmholtz Beamline-XFEL: Scientific Case

- Extending the scope of HED science at European XFEL
  → extremes of P, T, ρ, j, B- & radiation-fields

- Exploring new regimes of Strong-field Physics

- Particle- and radiation-driven Dynamic & Non-equilibrium Processes in materials, chemical- and biological-systems

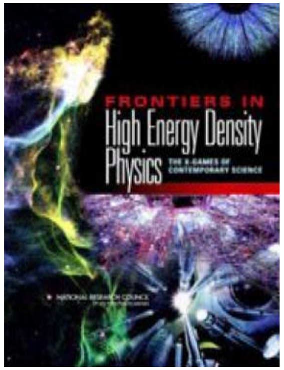
- Fundamental physics of ultra-intense laser-matter interactions for societally-relevant applied research

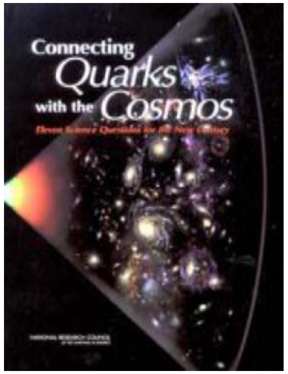
- Hard x-ray spectroscopy (XMCD, XAS) in magnetic materials and strongly correlated electron systems at high fields (50 T)

Helmholtz Beamline-XFEL: Scientific Case

Background: Science using kJ and PW lasers

- Nova, Vulcan, LULI, Phelix, Omega, NIF, LIL, Jupiter, Trident, Gekko XII, …





→ hard x-ray backlighting is an essential component of many experiments – complex targets, constraints on rep-rate, brightness, techniques, and quality

→ laser-drivers at 4th generation XFEL will be revolutionary

from shot-per-hour/day/year → to ~Hz rep-rate, shot-on-demand

from “demonstration” → to “precision & systematic” exploration

Helmholtz Beamline-XFEL: Scientific Case

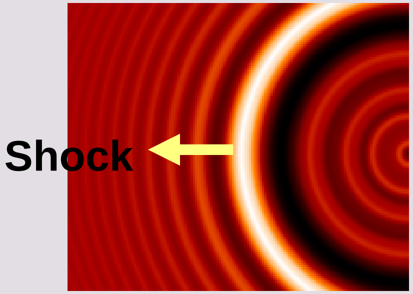
Targeted sessions on:

- Materials at extreme pressure
- Dynamics of particle damage
- Ultra-intense laser-matter interaction
- Strongly magnetized plasmas (lab astrophyics)
- Electron transport
- Particle Acceleration….

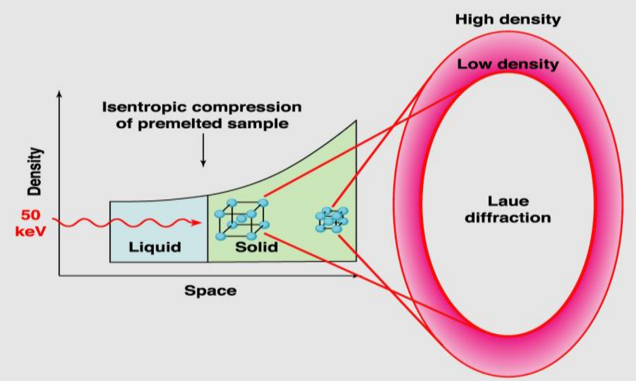
Broad interest in use of future Helmholtz Beamline at XFEL

XFEL combined with a high-power laser drivers will open a new frontier of Science at Extreme Conditions

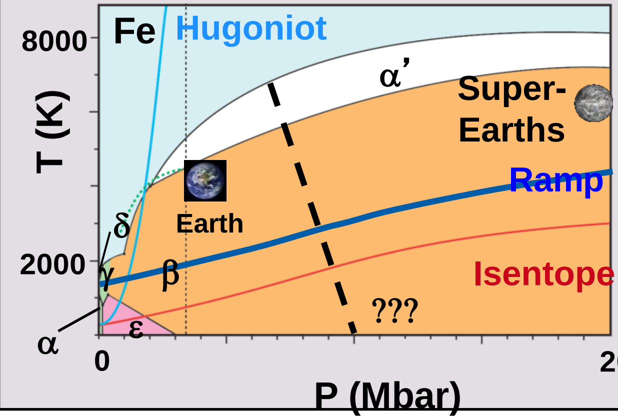
Diffractive imaging



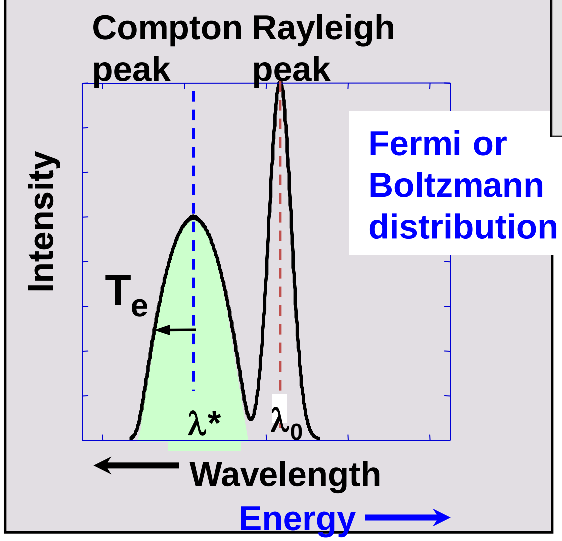
X-ray scattering => structure, chemistry, kinetics



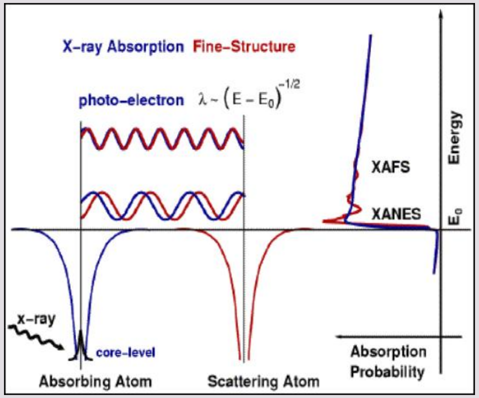
Thermodynamic states



Compton scattering Te,Z,ne,collision time of dense plasmas



X-ray absorption for Melt, Chemistry

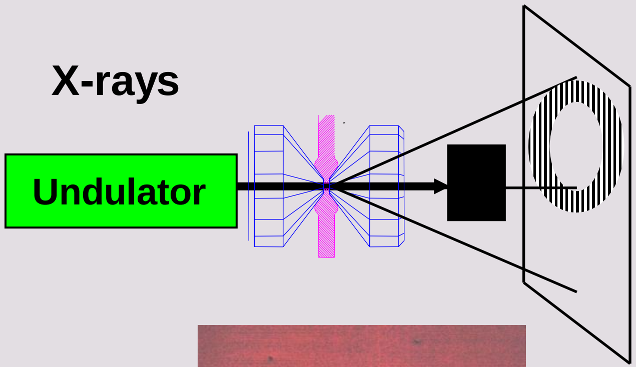


DRESDEN concept
HZDR

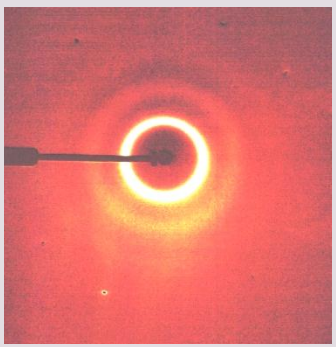
Courtesy G. Collins

XFEL will enable measurements of the structure factor in dynamic compression experiments

Liquid diffraction will be required for melt curves, coordination, bonding



Argon at 1 GPa 300 K

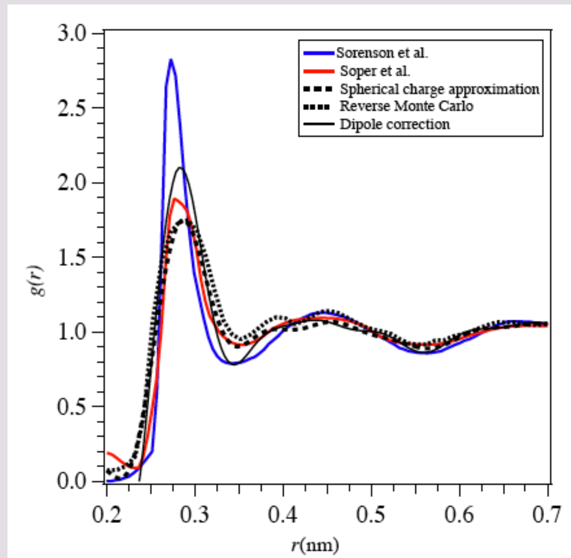


J. Eggert, 02

dynamic compression requires single shot or signal avg.

Radial distribution function in for compressed liquids

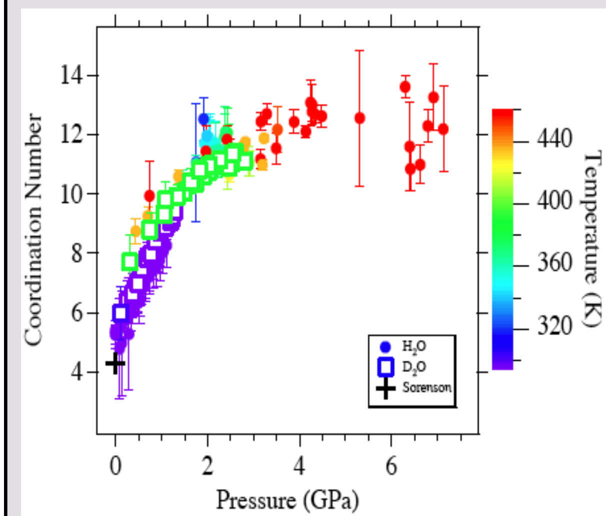
Eggert measured the Distribution function for H2O



This provides absolute density determination

Coordination of complex fluids

Coordination # obtained from g(r)

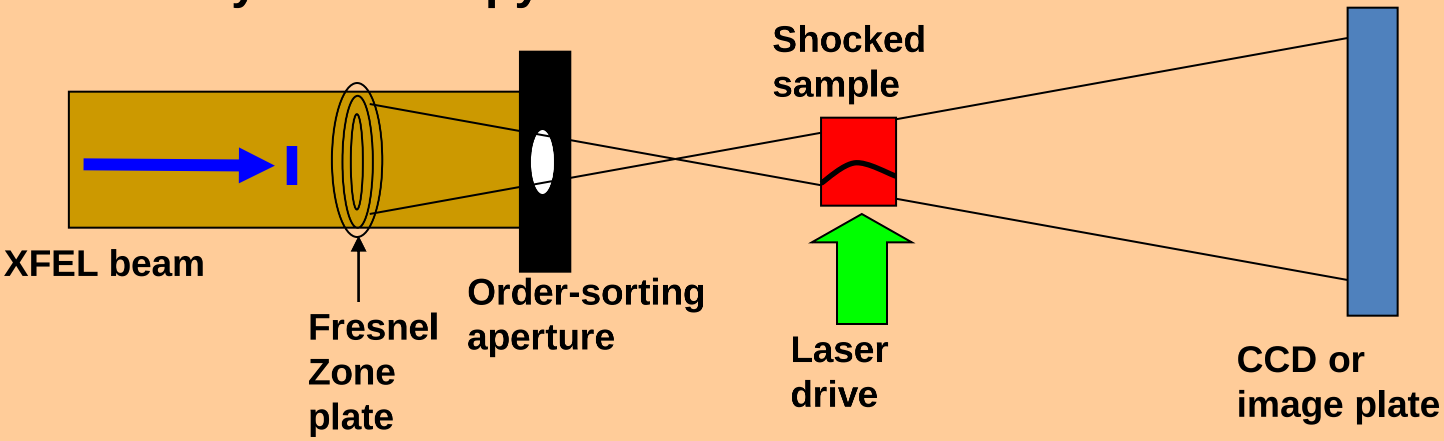


This combined with XANES or EXAFS will provide detailed bonding for complicated systems

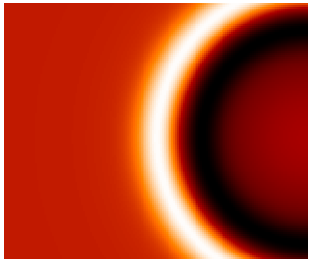
Courtesy G. Collins

Phase contrast and Coherent diffractive imaging on XFEL will connect atomic to mesoscale behavior of matter

In-line x-ray microscopy



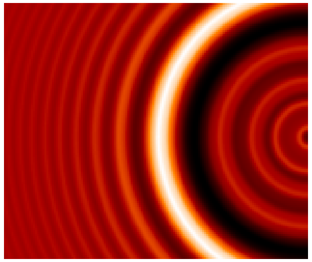
Shock front @ 2 μm resolution



Phase-contrast imaging (near-field)

Single-pulse imaging: 10^5-10^7 ph/pulse (resolution dependent)

Shock front @ 50 nm resolution



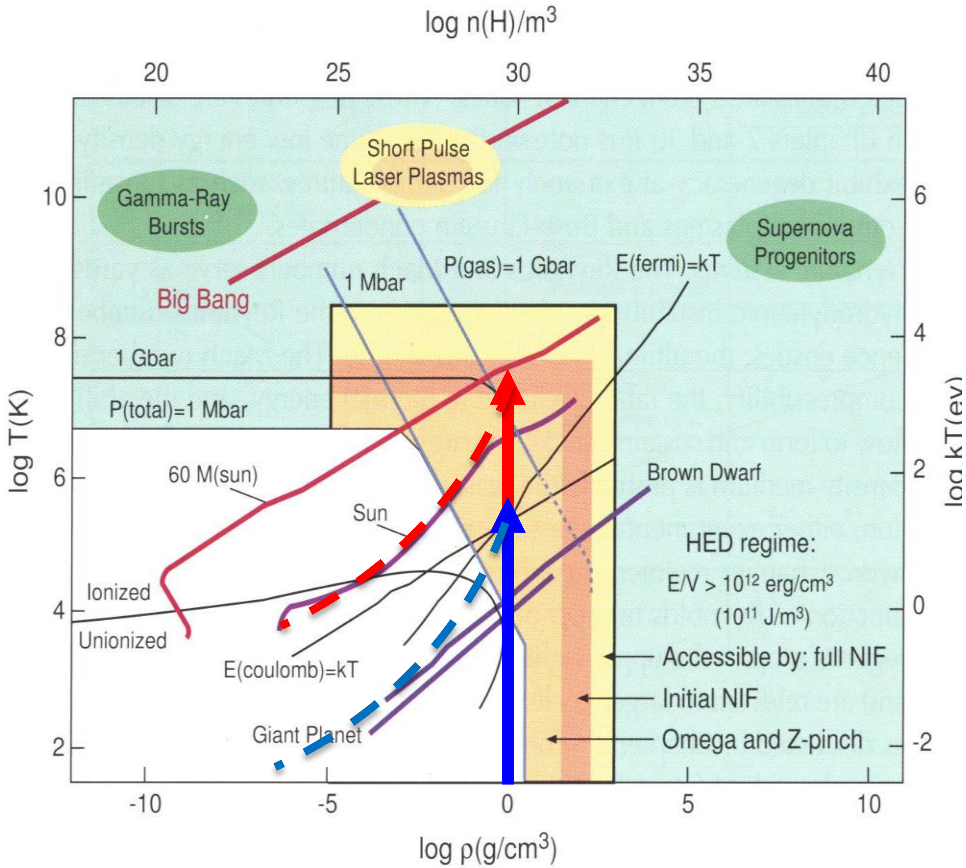
Coherent-diffractive imaging (far-field)

With sufficiently high beam coherence (i.e. high spatial resolution), Phase Contrast imaging → Coherent Diffractive imaging

Courtesy G. Collins

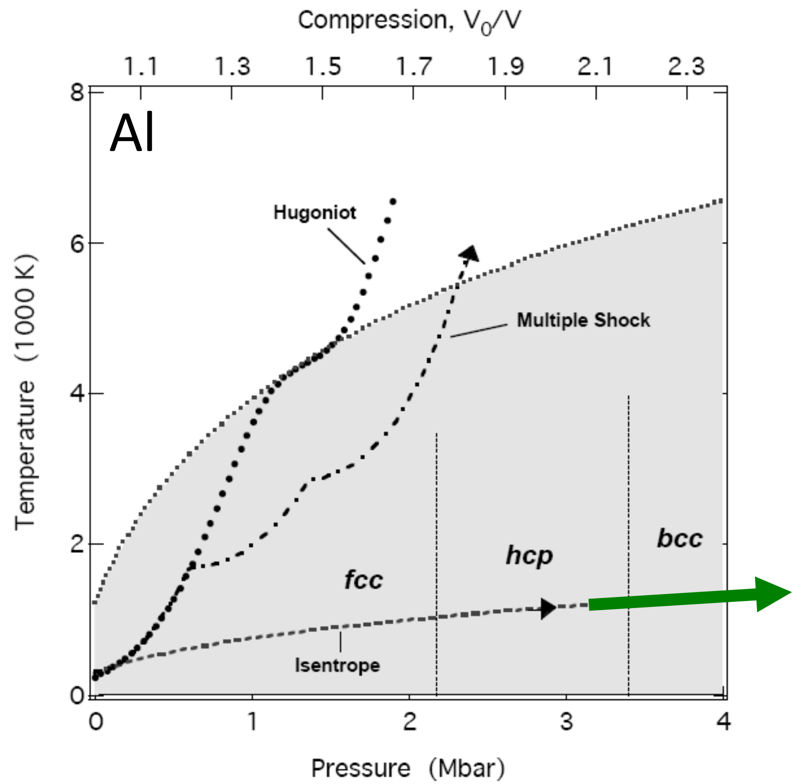
Helmholtz Beamline-XFEL: extending HED Science at XFEL

Isochoric Heating



- Short-pulse laser-driven
- XFEL-driven

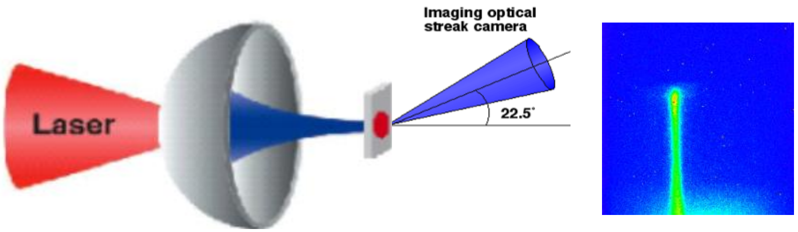
Compression



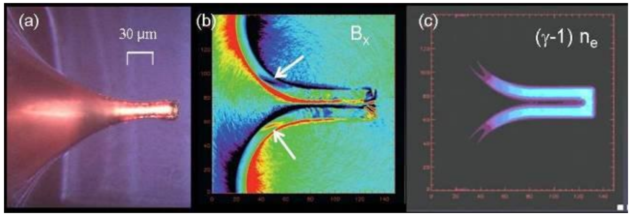
- Ramped (~kJ, ~ns) cold compression to TPa

Isochoric heating with ultra-intense short-pulse lasers

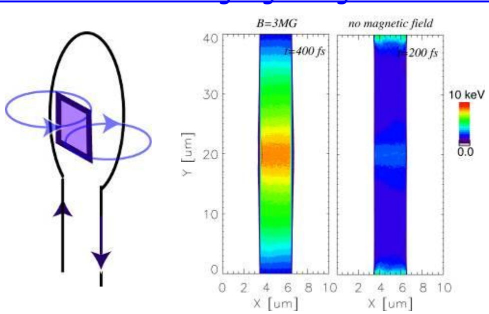
Isochoric heating with laser-accelerated protons
Patel *et al.*, Phys. Rev. Lett. **91**, 125004 (2003)



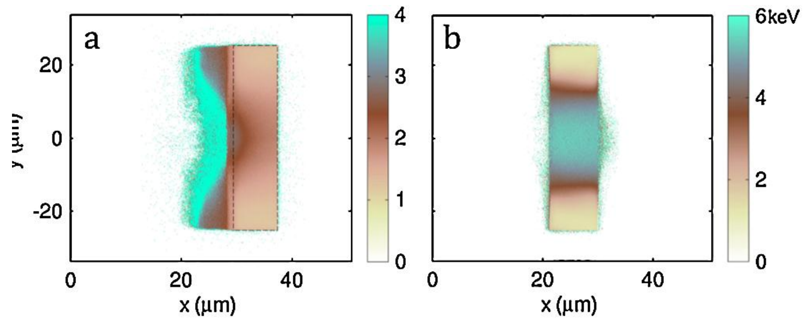
Self-generated magnetic confinement of hot electrons and enhanced heating
Rassuchine *et al.*, PRE **79**, 036408 (2009)



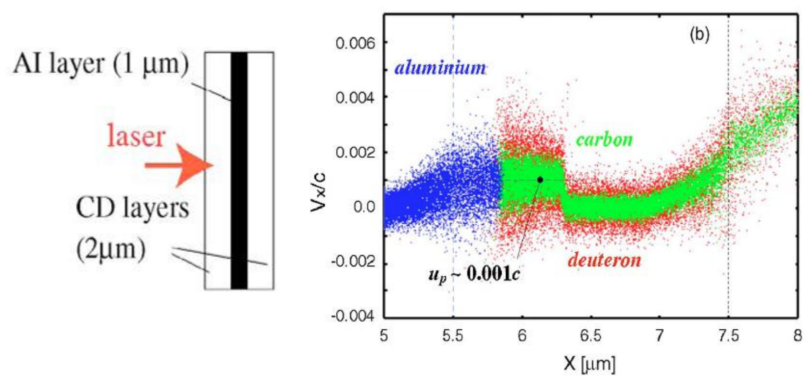
Pulsed external ~MG magnetic transport inhibition
Bakeman *et al.*, Megagauss XI (2007)
http://conferences.theiet.org/mg-xi/mgxi-final-v7.0.pdf



Electrostatic-confinement of hot electrons using reduced-mass targets
Perez *et al.*, Phys. Rev. Lett. **104**, 085001 (2010)



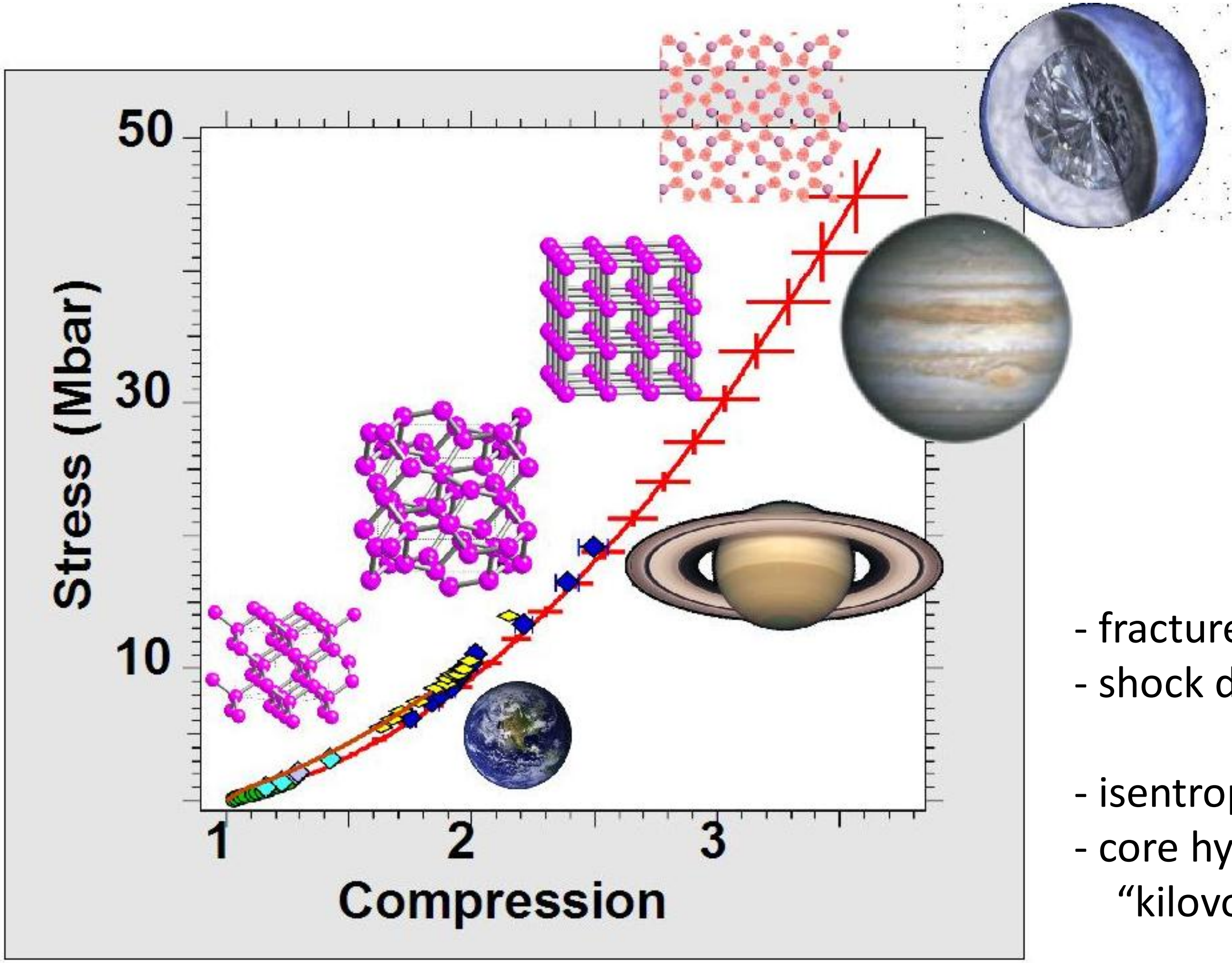
Interface shock heating in heterogenous targets
Sentoku *et al.*, Phys. Plasmas **14**, 122701 (2007)



→ ultrafast, focused, intense x-ray probe

DRESDEN concept
HZDR

Extreme States of Matter at High Compression



- fracture & deformation
- shock dynamics

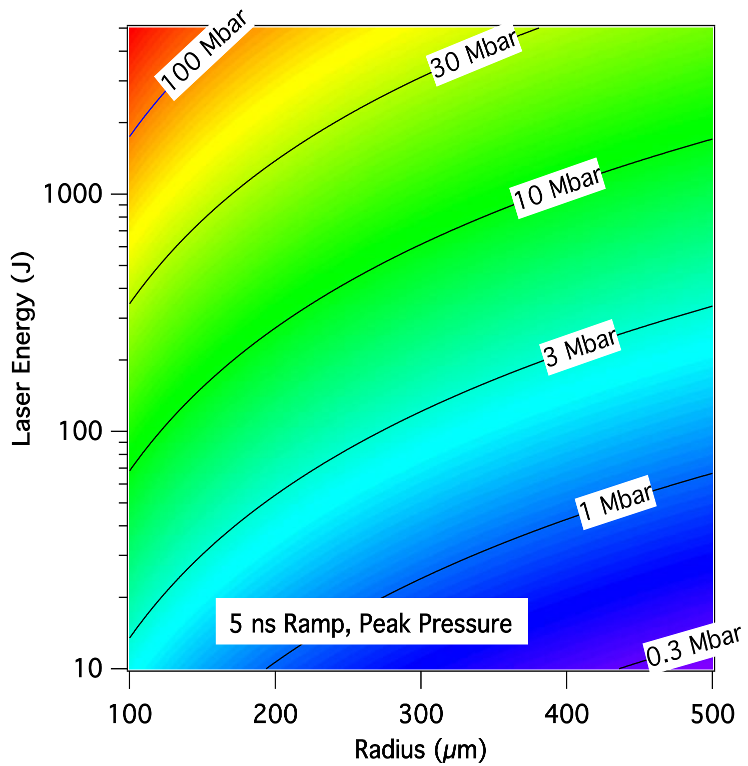
- isentropic compression
- core hybridization
  "kilovolt chemistry"

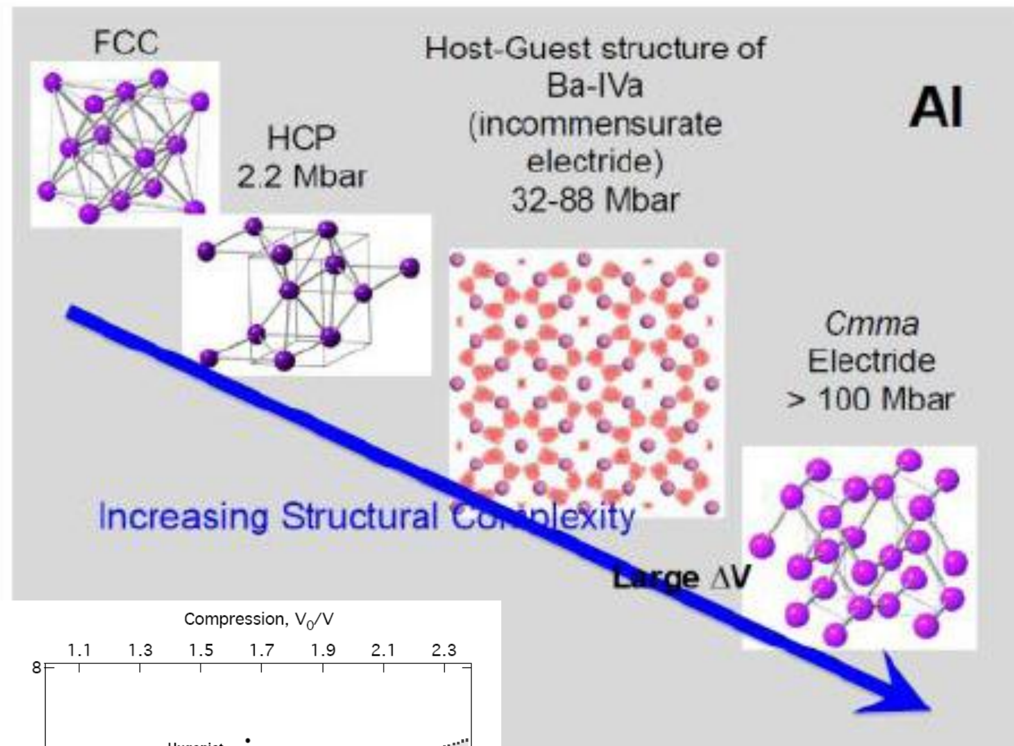
- "materials by design"

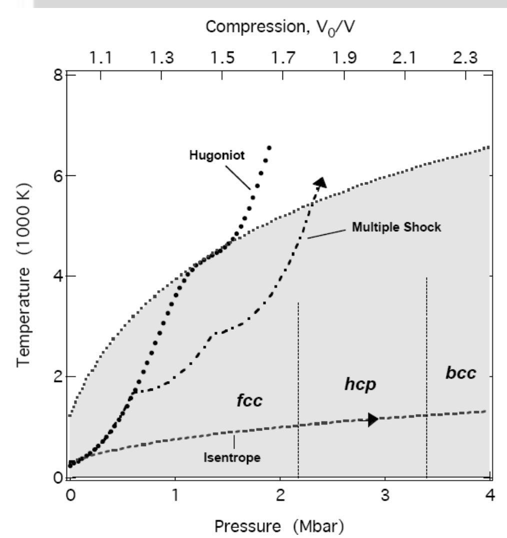
with Rostock, Oxford, DESY, Edinburgh, LLNL, LANL, LCLS, LULI, CEA, CELIA-Bordeaux, IOE-MUT

Courtesy G. Collins

Helmholtz Beamline-XFEL: Xray Science up to 4 Mbar and beyond





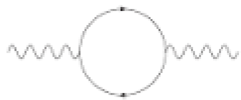


Strong Field Physics

Quantum Vacuum Polarization in Intense Fields

(H. Gies group, HI-Jena)

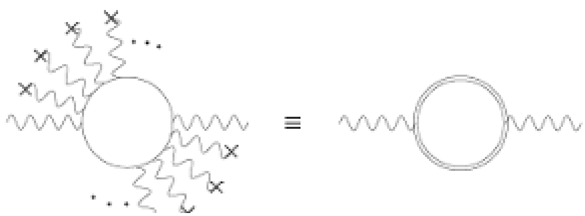
- 1-loop polarization tensor (in the absence of external fields)

$\Pi^{\mu\nu}(k) =$ 

- in the presence of an external field

  → 1-loop polarization tensor

external field : 



$\Pi^{\mu\nu}$ is the central input to an effective theory for photon propagation in the quantum vacuum

$$\mathcal{L}_{\text{eff}}[A] = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\int_{x'} A_\mu(x)\,\Pi^{\mu\nu}(x,x')\,A_\nu(x')$$

↑ vacuum fluctuations

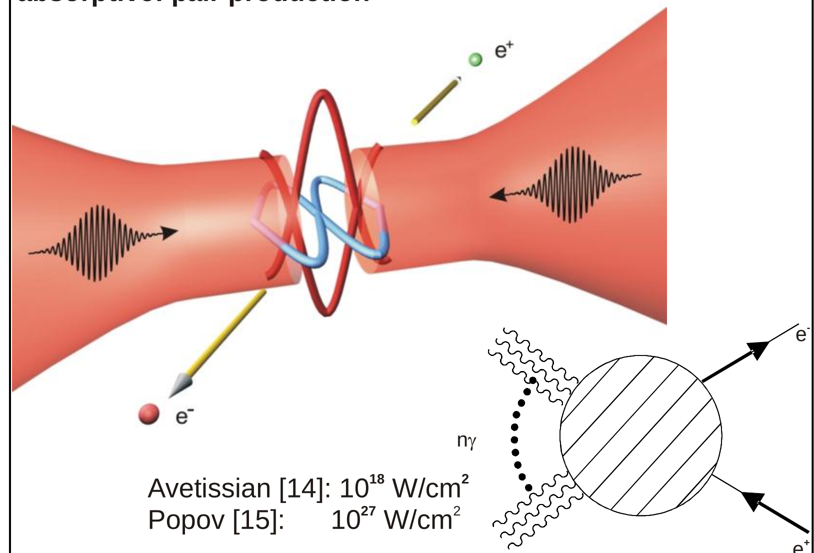
(here A_μ denotes a classical, macroscopic field)

without external fields: $\Pi^{\mu\nu}$ easily evaluated in momentum space

↔ in the presence of (constant) external fields: rather involved

- accounts for absorptive/dispersive effects in external fields

absorptive: pair production



effects and problems to be investigated:

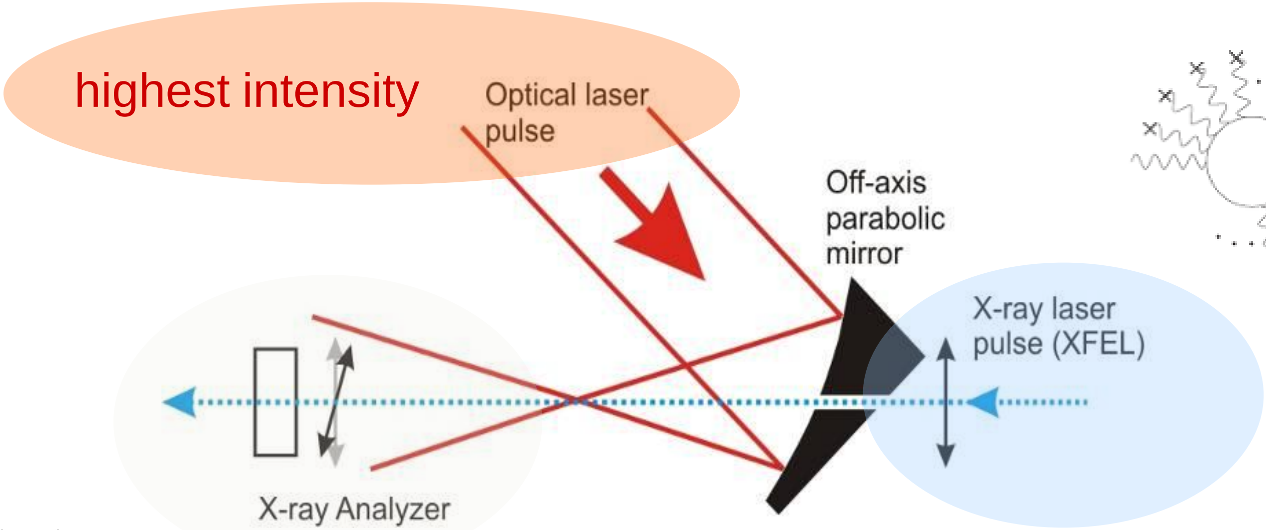
- deformation of light cone, birefringence, polarization effects
- nonpertubative QFT in strong laser fields
- photon-photon scattering
- electron-positron pair creation (in vacuum), ...

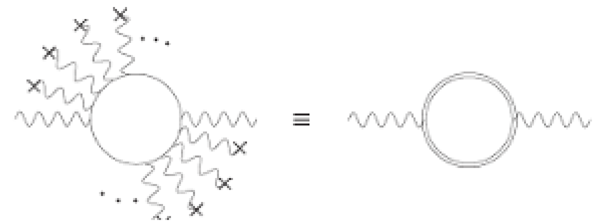
- Vacuum birefringence:

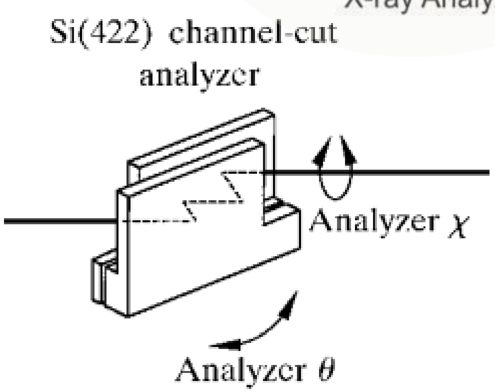
  Th. Heinzl, R. Sauerbrey, *et al.,* Opt. Commun. 267, 318 (2006)

E.g., Birefringence of QED Vacuum

T. Heinzl, *et al*, Opt. Com. 267 (2006) 318







at 15 keV, 10^{22} W/cm²

Phase shift:

$$\Delta\phi = 2\pi \frac{d}{\lambda_{probe}} \cdot \Delta n = \frac{4\alpha}{15} \frac{d}{\lambda_{probe}} \cdot \frac{I}{I_c}$$

~3.5 10^{-5}

Intensity (vs. full extinction):

$$\delta^2 \sim (\Delta\phi/2)^2 \sim \omega_{probe}^2 \cdot \left(z_0 \frac{I}{I_c} \right)^2$$

~3 10^{-10}

polarized X-ray probe

high intensity and interaction length

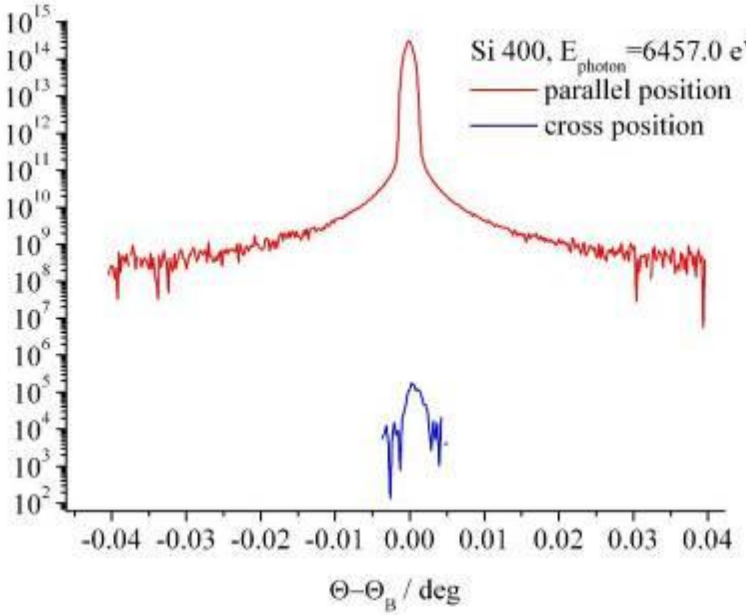
with IOQ-Jena, HI-Jena, HZDR, LCLS.
other concepts: MPIK-HD, Oxford, LLNL, GSI, Umea Univ, LMU-Munich

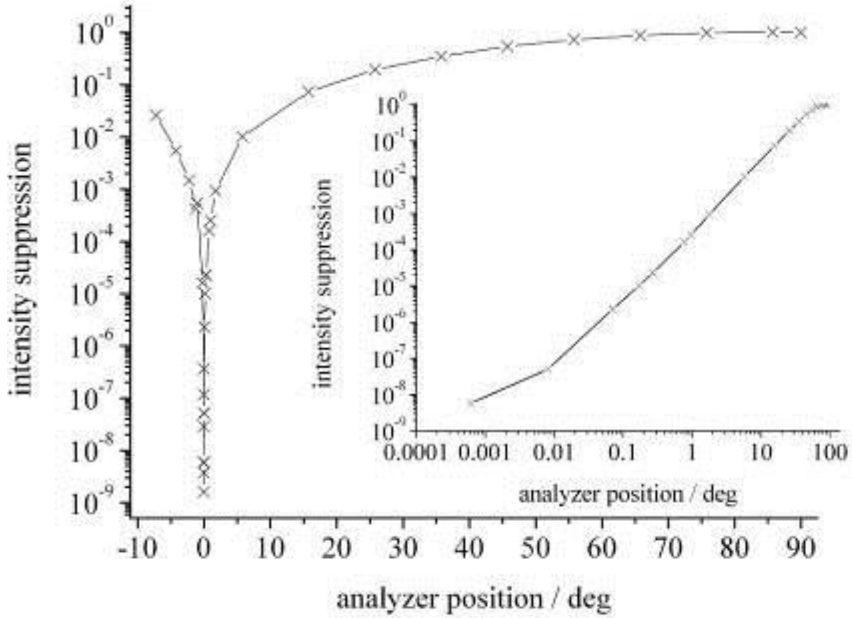
Realization – channel-cut Bragg crystal polarimetry

I. Uschmann et al, "Determination of high purity polarization state of x-rays," ESRF expt. (2010)

(5×10^{-10} polarization)

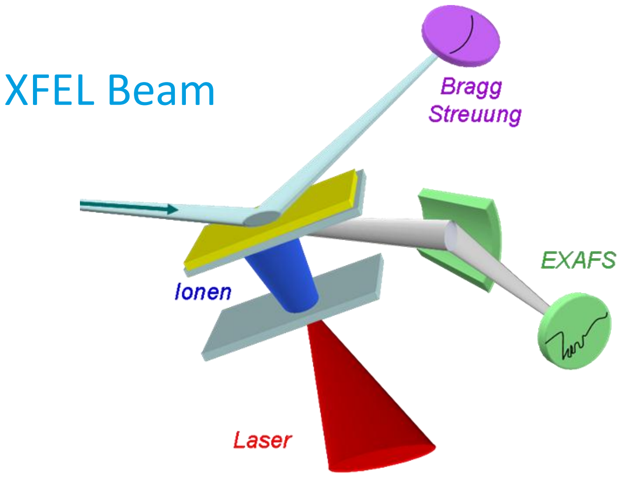
Channel cut Si 400 crystal





Dynamics of particle-induced damage

GOAL: Predictive understanding of ion-induced damage, by experimental bench-marking & validation of MD calculations of full dynamics



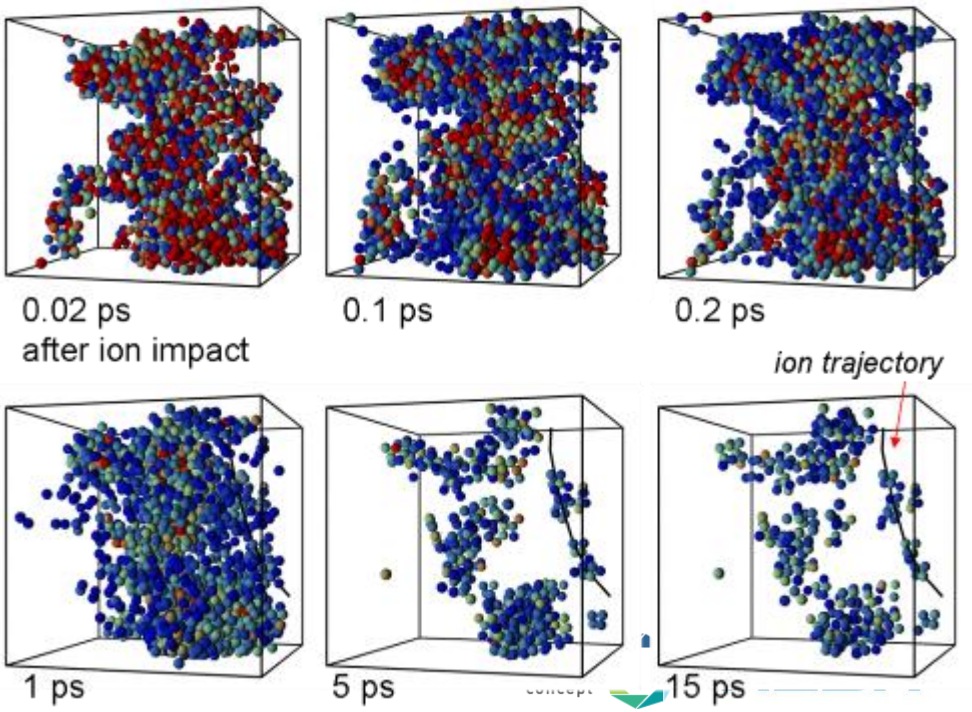
- **Ion implantation damage**

- **Fast neutron damage**

Ion-induced damage:

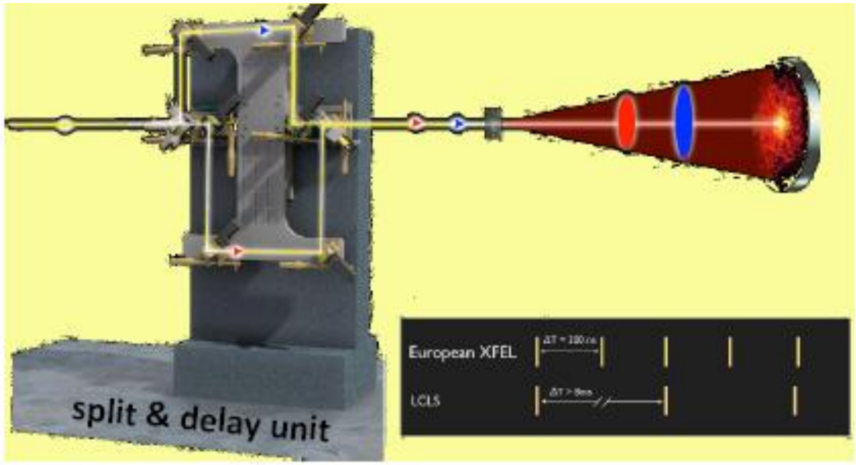
- knock-ion cascade
- local melt
- refreezing
- residual defects

- also, electronic heating (electron-phonon coupling)



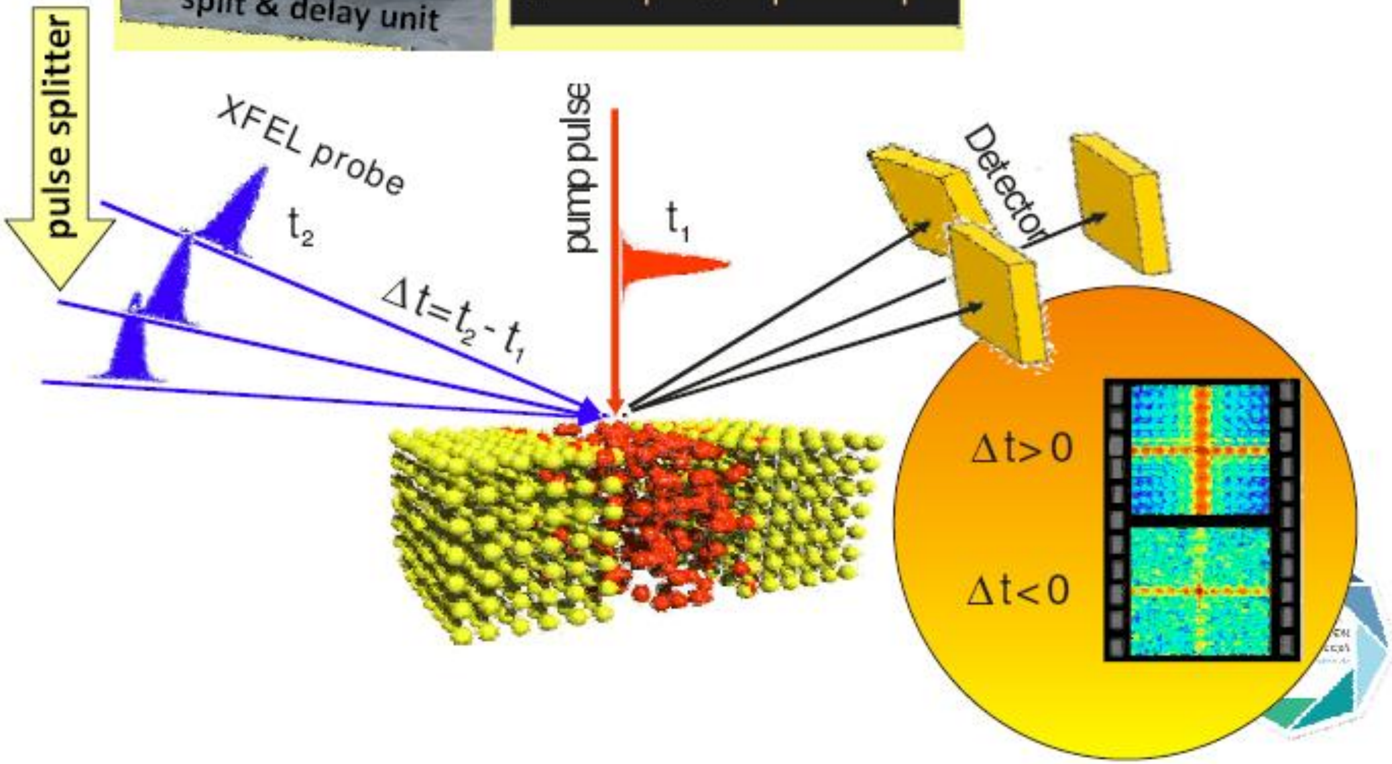
with PSI, ORNL, HZDR, LANL, LLNL, ILE-Osaka, HiPER, ELI

Dynamics of particle-induced damage



longitudinal coherence!

slow detector: sum of two speckle patterns
or very fast detectors (streak camera >200fs)
or different incidence/exit angles



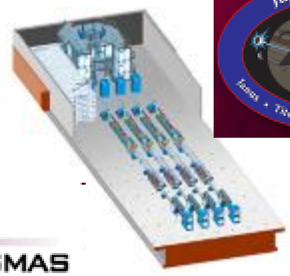
HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

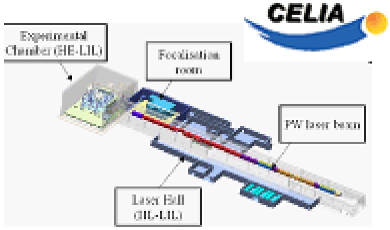
Concept: G. Grübel, G.B. Stephenson, C. Gutt, H. Sinn, T. Tschentscher, NIM B 262, 357 (2007)
realized: W. Roseker et al. Optics Letters 34, 1768 (2009)

Dr. J. Grenzer I FWI I www.hzdr.de

Ultra-Intense Laser-Matter Interactions

Rapidly growing community of PW laser research worldwide…





Penelope, Phelix, Polaris, Draco-PW, Vulcan, AstraGemini, SCAPA, Jupiter, Trident, Omega-EP, PETAL, ILE, ELI, LFEX,… CILEX

Many prospective applications…

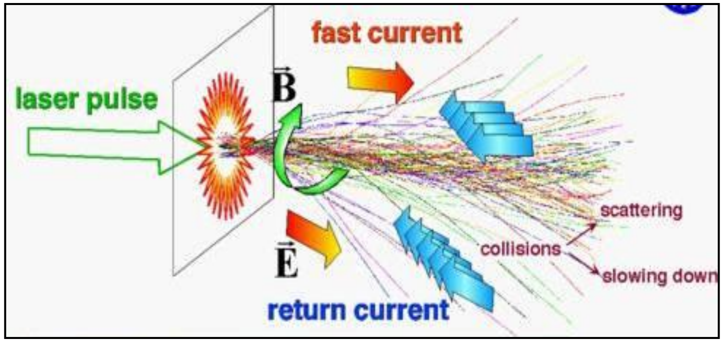
- Compact accelerators
- Table-top light sources
- Isochoric heating
- Fusion Energy
- Radiation research in Oncology
- Ultrafast Science

→ Physics inside of solid-density plasma:

particle transport, filamentation, ionization dynamics, extreme self-fields, return currents, e-e & e-i relaxation, heating, resistivity, magnetic diffusion, …

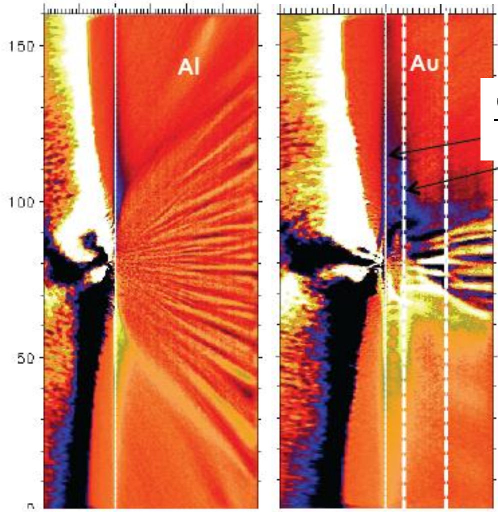
Electron transport & strong fields in laser-driven targets

Extreme current densities, magnetized current filaments, and strong quasi-static resistive fields in ultra-intense laser-matter interactions



10^{13} A/cm^2, > 1000 T, 10^{13} V/m, ~keV solid density

→ **Current filamentation**



$$\frac{\partial B}{\partial t} = \eta \nabla \times J + \nabla \eta \times J$$

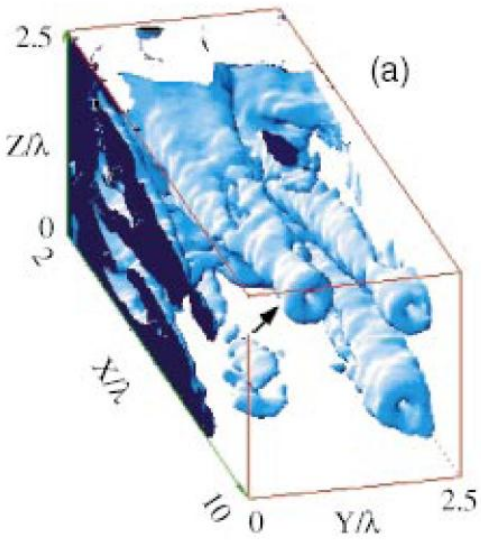
Important Questions:

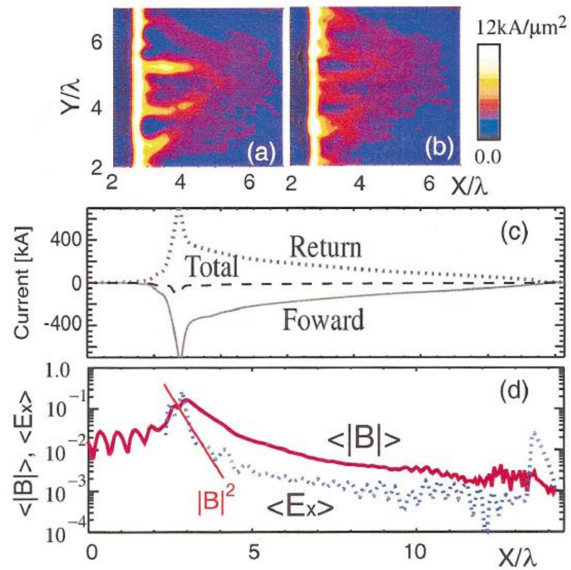
- return-current generation, neutralization (ionization, resistivity, heating)
- filament formation & propagation
- particle & energy transport
- quasi-static resistive fields
- magnetic diffusion (relaxation, >6 ps)
- e-e & e-i equilibration
- material dependence
- dependence on laser-intensity……

- Extreme transients & gradients
- Transition through cold-WDM-hot
- Extreme magnetizations

→ Ultrafast probing of B, Z*, j_e, T_e, inside solid-density plasma, time & space resolved

Helmholtz Beamline-XFEL: Filamentation instabilities





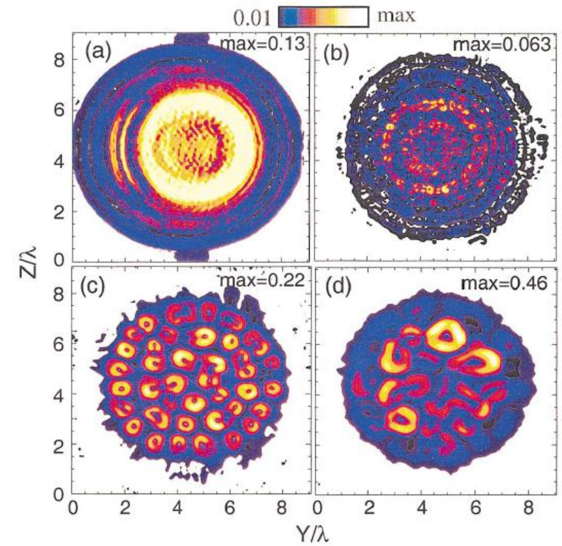
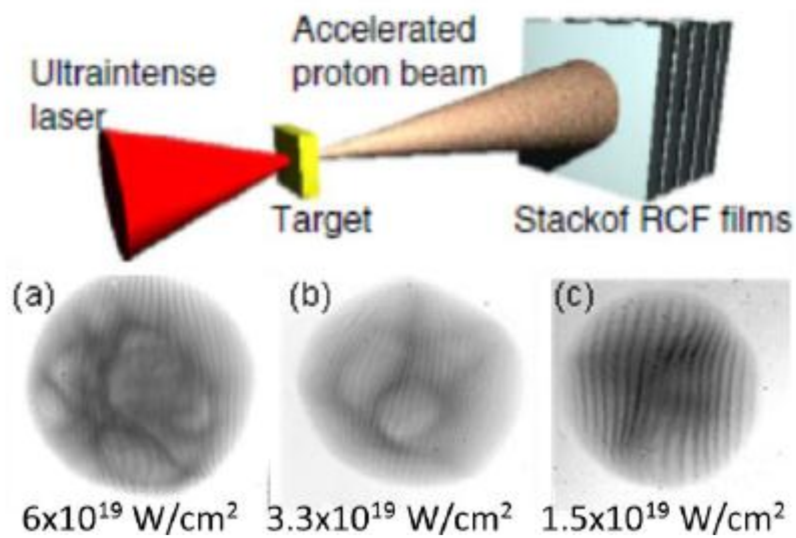


FIG. 1 (color). Transverse cut of $|E_\perp|$ at $t = 4\tau$ (a) and $|B_\perp|$ at $t = 5$ (b), 15 (c), 25 (d). Each plot is observed at $X = 2.85\lambda$.

Y. Sentoku et al, PRE 65, 046408 (2002); PRL 90, 155001 (2003)

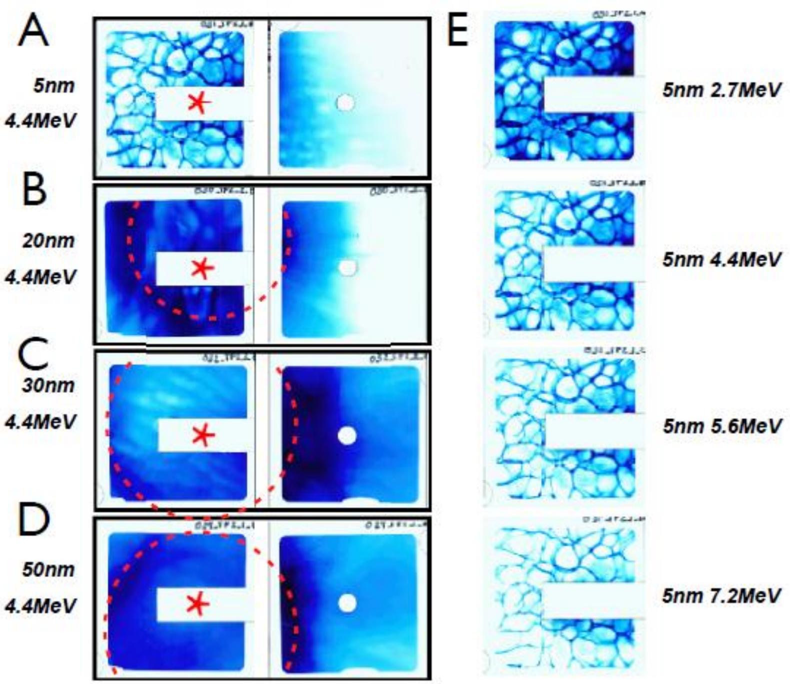
P Antici et al, JPCS 244, 022016 (2010);
Y Sentoku et al, PRL 107, 135005 (2011);



Affects laser-accelerated proton beam quality at highest laser intensities….

Helmholtz Beamline-XFEL: Proton beam filamentation

Proton beam disruption for thinnest targets
Palmer et al, PRL accepted…



Rayleigh-Taylor Instability of an Ultrathin Foil Accelerated by the Radiation Pressure of an Intense Laser

C. A. J. Palmer[1], J. Schreiber[1,2,3], S. R. Nagel[1], N. P. Dover[1], C. Bellei[1], F. N. Beg[4], S. Bott[4], R. J. Clarke[5], A. E. Dangor[1], S. M. Hassan[6], P. Hilz[3], D. Jung[3], S. Kneip[1], S. P. D. Mangles[1], K. L. Lancaster[5], A. Rehman[1], A. P. L. Robinson[5], C. Spindloe[5], J. Szerypo[3] M. Tatarakis[6], M. Yeung[7], M. Zepf[7], Z. Najmudin[1]
[1] *The Blackett Laboratory, Imperial College London SW7 2BW, United Kingdom*
[2] *Fakultät für Physik, Ludwig-Maximilians-Universität München, D-85748 Garching, Germany*
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[5] *Central Laser Facility, Rutherford Appleton Laboratory, Oxon, United Kingdom*
[6] *Laboratory of Optoelectronics, Lasers and Plasma Technology, TEI Crete, Chania, Crete, Greece and*
[7] *Queen's University Belfast, Belfast, United Kingdom*
(Dated: April 5, 2012)

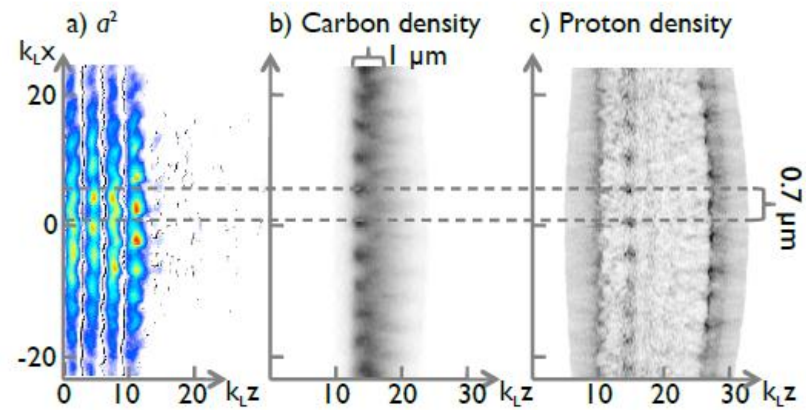
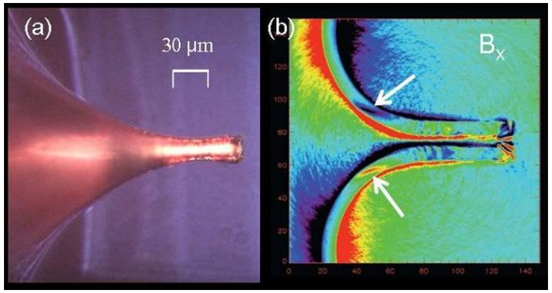


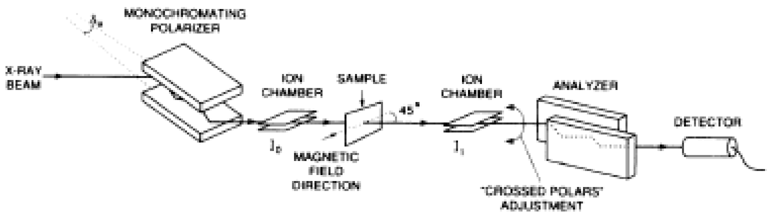
FIG. 4. (colour online) Simulation snap-shots of a) laser intensity, $\langle a^2 \rangle$; b) carbon ion density ; and c) proton density for a simulation with $d = 10$ nm (312 fs after the pulse first reaches the target).

Rayleigh-Taylor , or Relativistic electron filamentation ?

B-field imaging in solid-density plasma by x-ray Faraday rotation

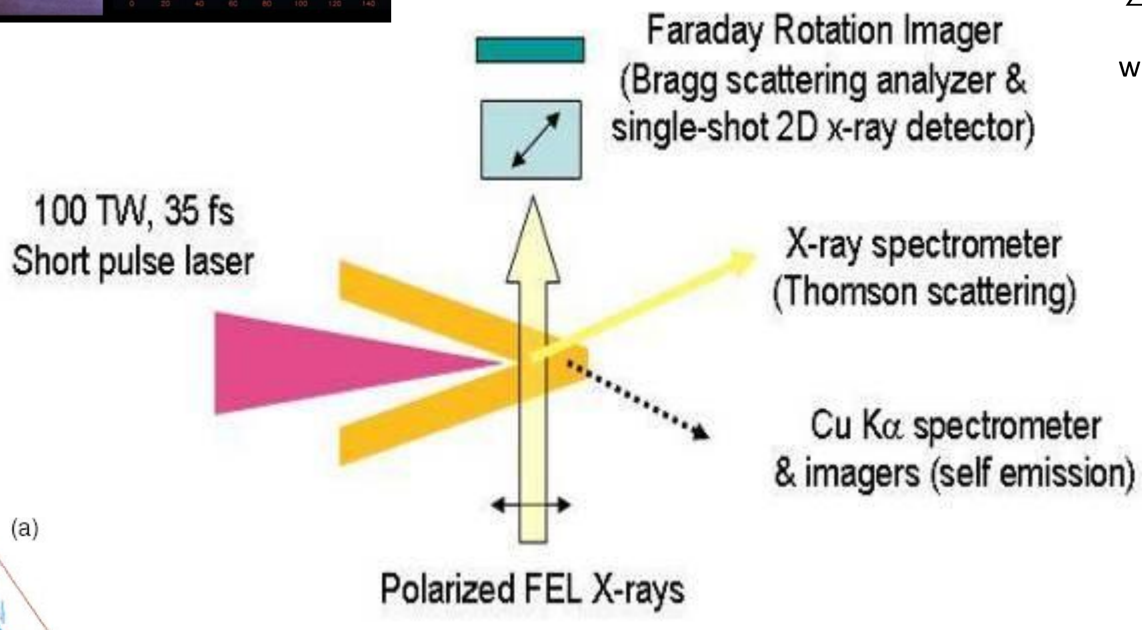
5000 Tesla quasi-static field → x-ray Faraday rotation imaging



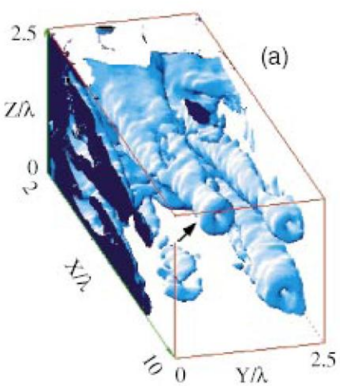


$$\Delta\varphi \approx K\lambda^2 \int n_e B_z dz$$

with K= 2.629×10^{-13} M.K.S. units.

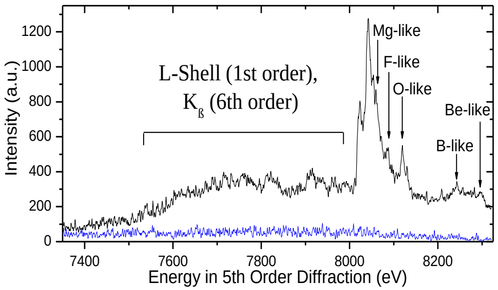


Channel-cut Si cyrstals:
I. Uschmann *et al*, HI-Jena

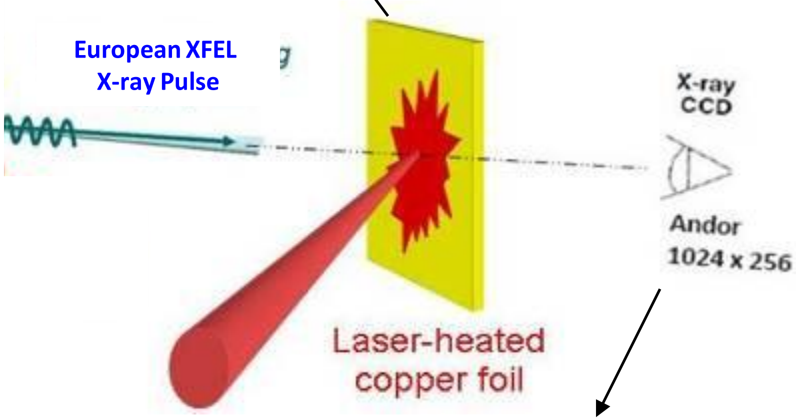


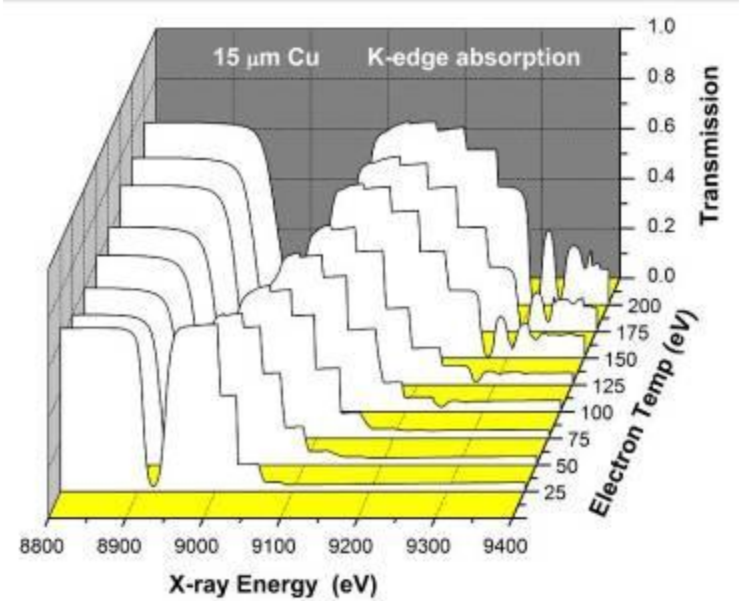
Apply to filamentation...

Ionization dynamics & heating by 2D space-resolved XAS

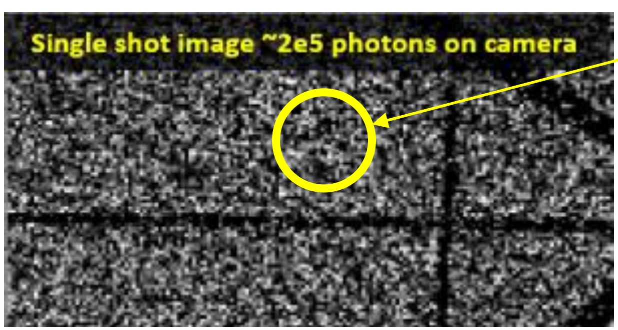


Self emission spectroscopy Δt
~ 5-10 ps





Locally-averaged spectrum



Bulk electron temperature
T_{bulk} (x, y, t)

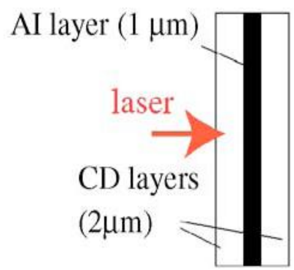
with D. Thorn, T. Stoehlker (HI-Jena, GSI), M. Harmond, S. Toleikis (DESY)

Shock heating at material interfaces

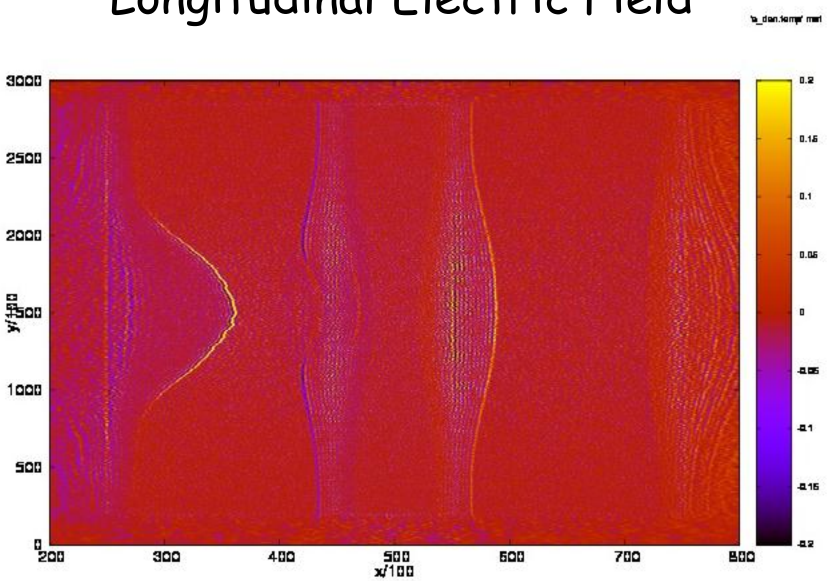
黄林根

Detailed simulations of “shock” heating in CD_2/Al/CD_2: Lingen Huang, T. Kluge, M. Bussmann, et al.
and planning for HZDR/LLNL/STFC experiment: B. Ramakrishna, R. Shepherd et al.

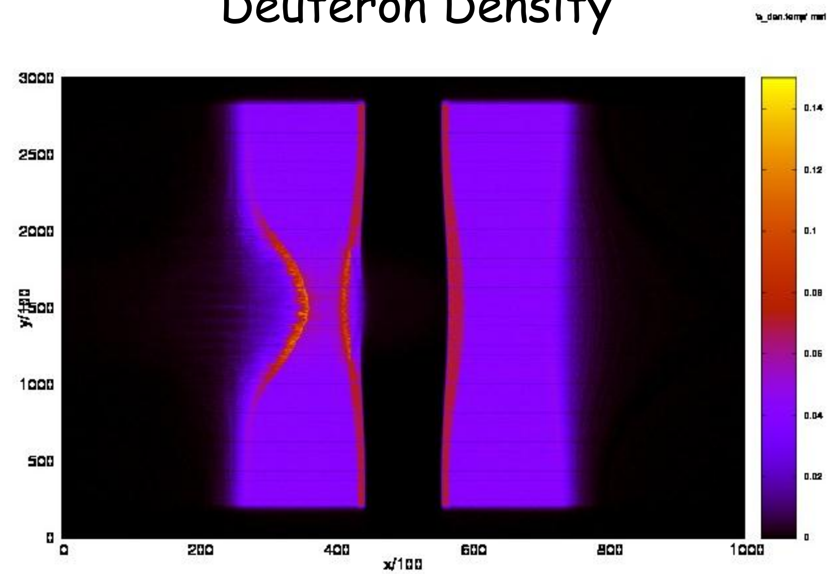
10^{20} W/cm^2 150 fs



Longitudinal Electric Field



Deuteron Density

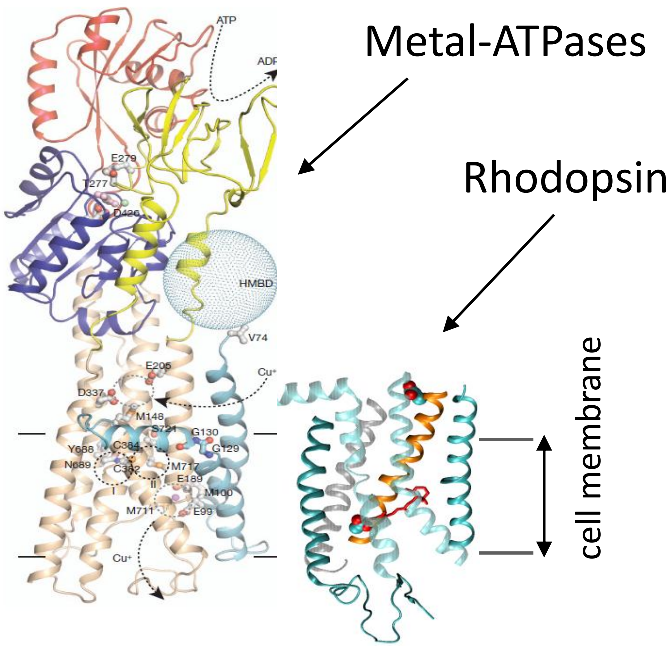


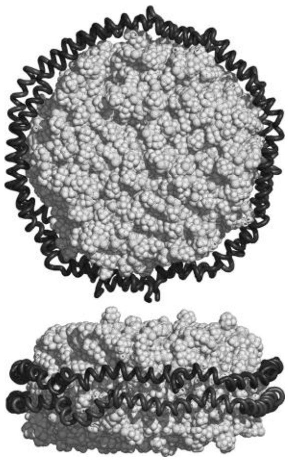
based on:
“Isochoric heating in heterogenous solid targets with ultrashort laser pulses,”
Y. Sentoku, A. Kemp, R. Presura, M. Bakeman, T.E. Cowan, Phys. Plasmas **14**, 122701 (2007)

DRESDEN concept HZDR

Additional prospects at European XFEL

- Structural Biology → membrane protein functionality in radiobiology
  - Fahmy, Barty, Dubrovska, Sakmar *et al*, (HZDR, CFEL, OncoRay, Rockefeller, …)





- High-field X-ray Magnetic Circular Dichroism
  - XFEL allows use of ms-duration pulsed magnets
  - →~50 T pulsed magnets added to HGF Beamline

- Magnetized solid-density plasma & Compressed Matter

Summary

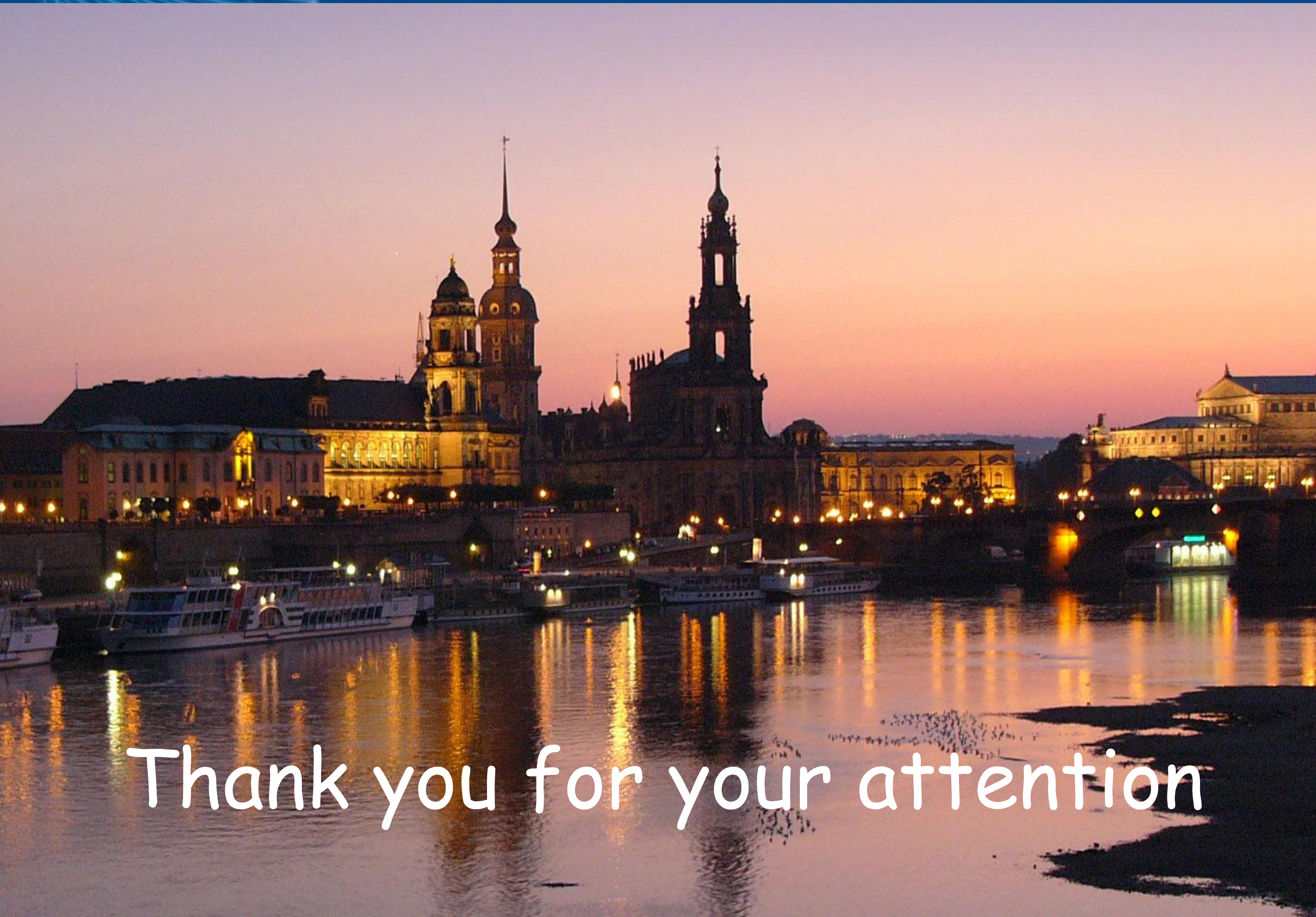
Helmholtz Beamline at European XFEL will provide many New Scientitic Opportunities

- Matter at extremes of P, T, ρ, j, B- & radiation-fields
- New regimes of Strong-field Physics
- Particle- and radiation-driven structural dynamics
- Physics of ultra-intense laser-matter interactions
- Hard x-ray spectroscopies at highest magnetic fields

→ laser- & high field-drivers at XFEL will be revolutionary

from shot-per-hour/day/year → to ~Hz rep-rate, shot-on-demand

from "demonstration" → to "precision & systematic" exploration


Thank you for your attention