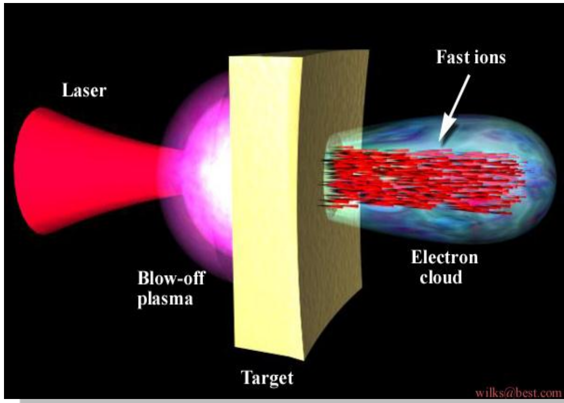
User Consortium for the Helmholtz Beamline at the European XFEL

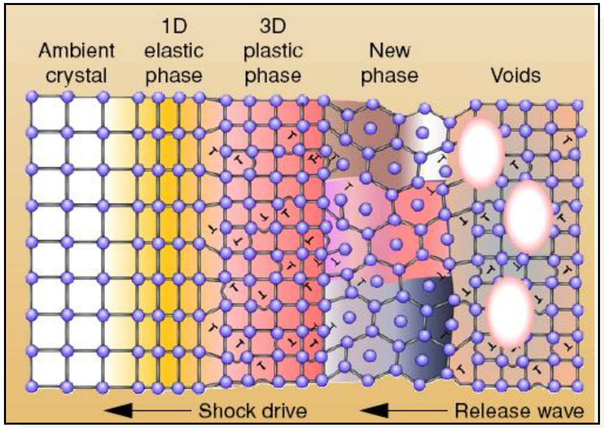
European XFEL
Science Advisory Committee Meeting
15. May 2012
Hamburg

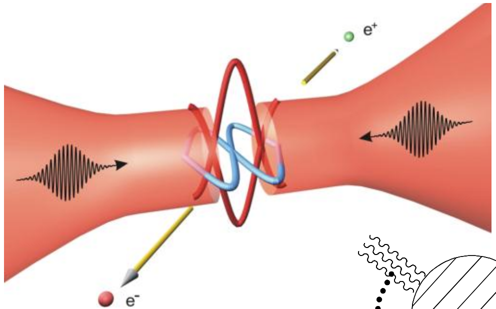
Helmholtz Beamline-XFEL: Ultra-intense & High-energy Lasers

Extreme particle beams

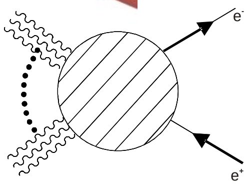


Extreme pressures

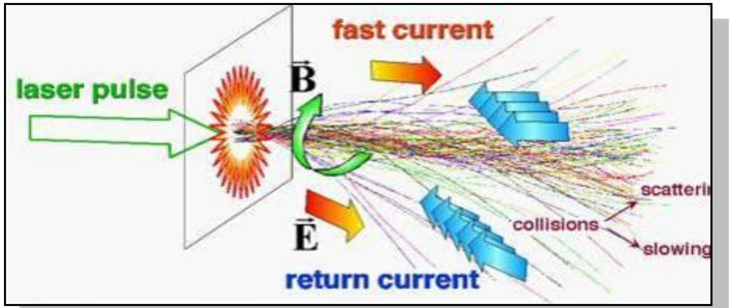


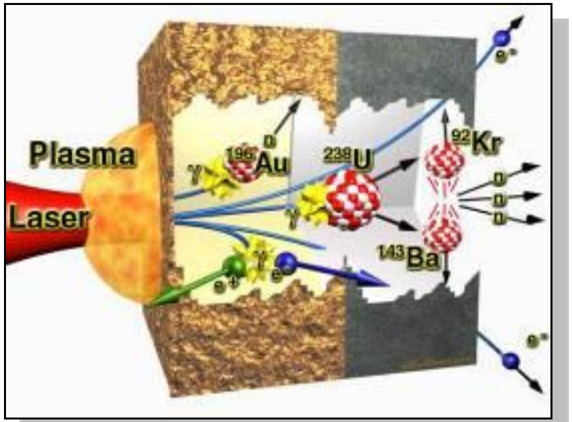


Strong Fields



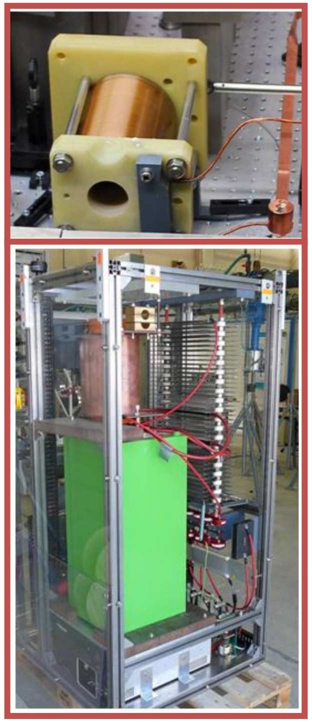
Extreme currents

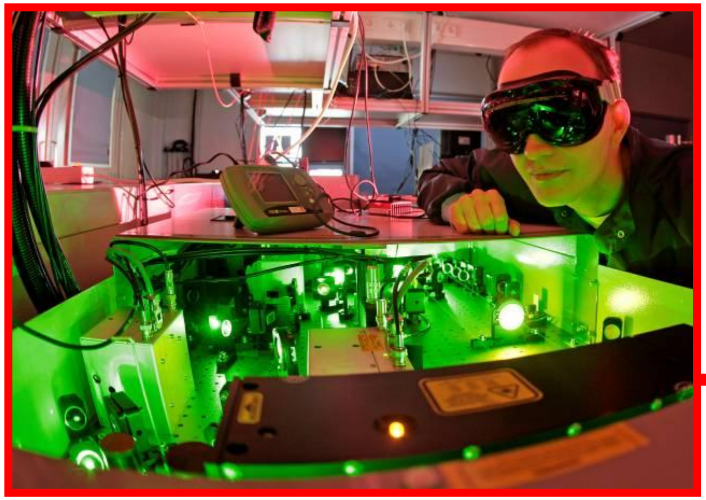




Extreme radiations

Helmholtz Beamline at the European XFEL

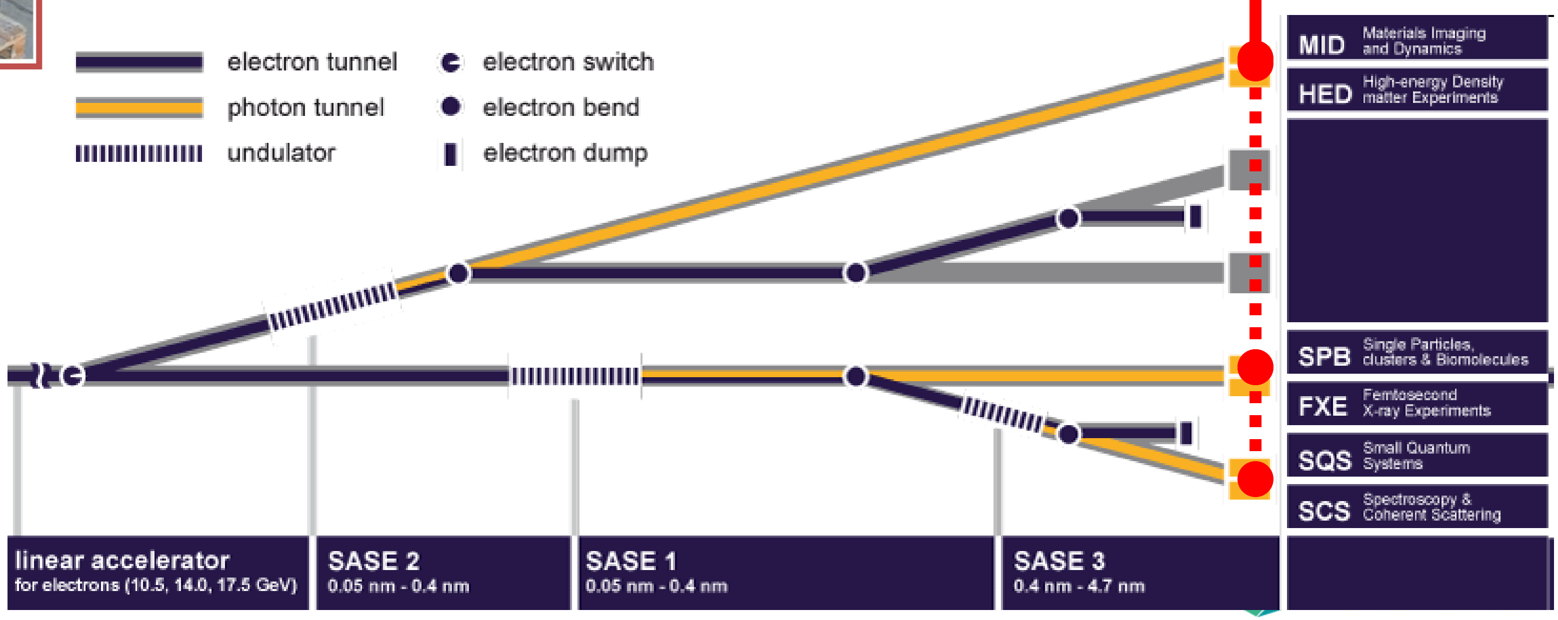




Laser Options (~0.1 – 10 Hz)
- ~PW, 150J/150 fs DPSSL
- ~PW, 30 J/30 fs Ti:Saph
- ~kJ, ~1-10 ns shaped

Pulsed Magnets (1 ms, ~50 T)

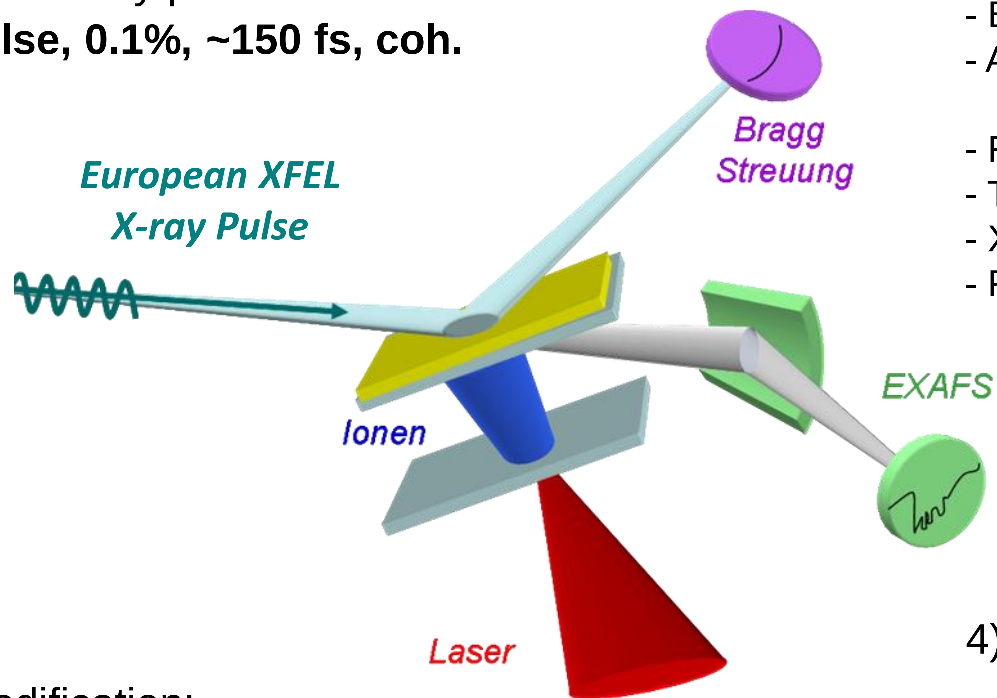
Optional target chamber for expt. staging



Helmholtz Beamline-XFEL: 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 dynamics

- Fundamental physics of ultra-intense laser-matter interactions

- Magnetic processes with hard x-rays & high fields (50 T)

Helmholtz Beamline-XFEL: Science & Facility

- Science → making <u>unique</u> use of XFEL x-ray capabilities

  - Single-pulse → intensity, pulse width, brightness, coherence, polarization
    (also available at other X-FEL's)

  - Bunch train → <50 fs synch., multi-user operation, 600 μs macro-pulse
    (unique to European XFEL)

  → Best x-fel worldwide for low-rep-rate & shot-on-demand experiments
  → Best x-fel worldwide for complex, multi-pump/probe, ultrafast phenomena
  → Only hard x-ray source worldwide for research with *highest* B-fields

  Unique opportunity worldwide, for integrating high-power-laser & high-field-magnet experiments with hard x-ray FEL

- User Facility (!) – reliable routine multi-user operation (few-shift expts)
  - Established laser technologies
  - Conservative operation (e.g., at <80% of damage threshold)
  - 2015 start, flexibility for upgrades

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

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

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

DRESDEN concept HZDR

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

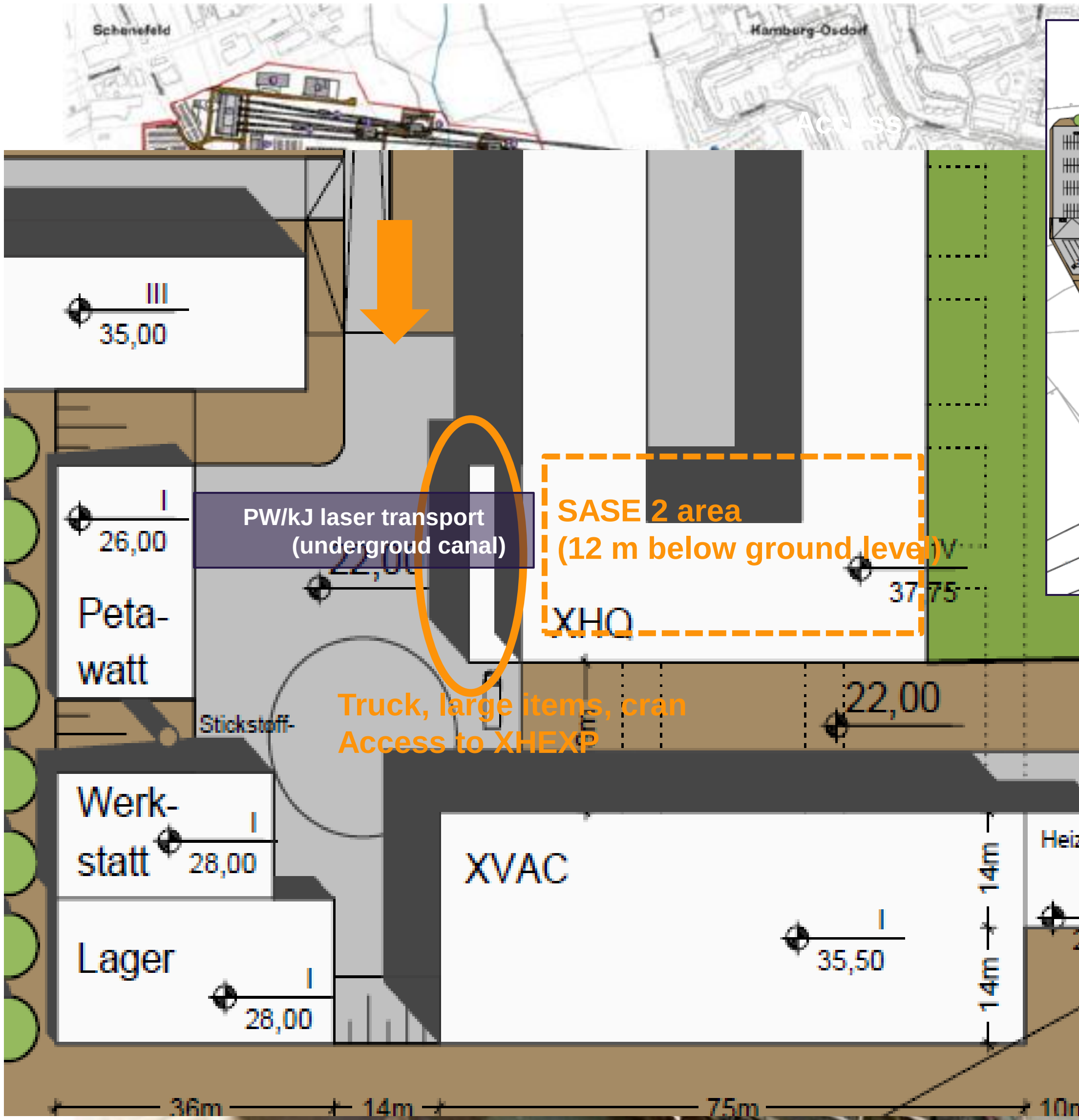
Faculty/Groups	86
Institutions	63
Faculty/Staff/Students	678

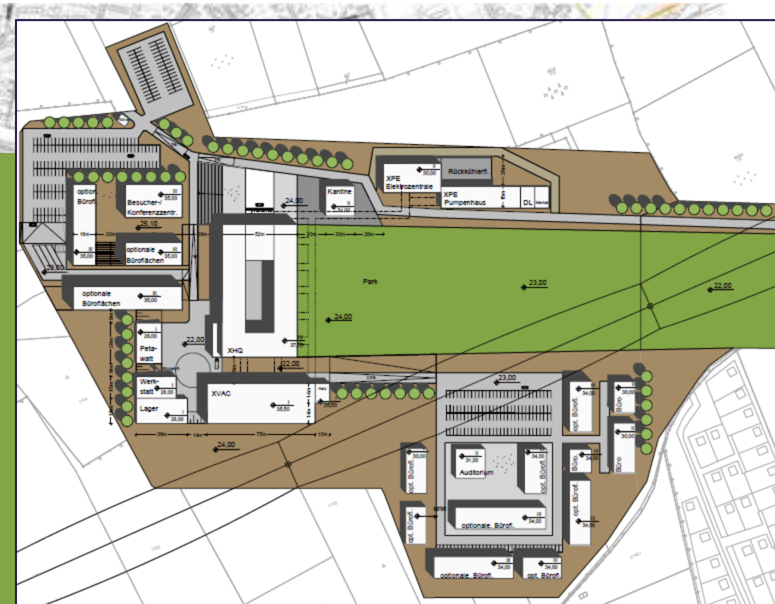
Helmholtz-Beamline at European XFEL – Partner Contributions

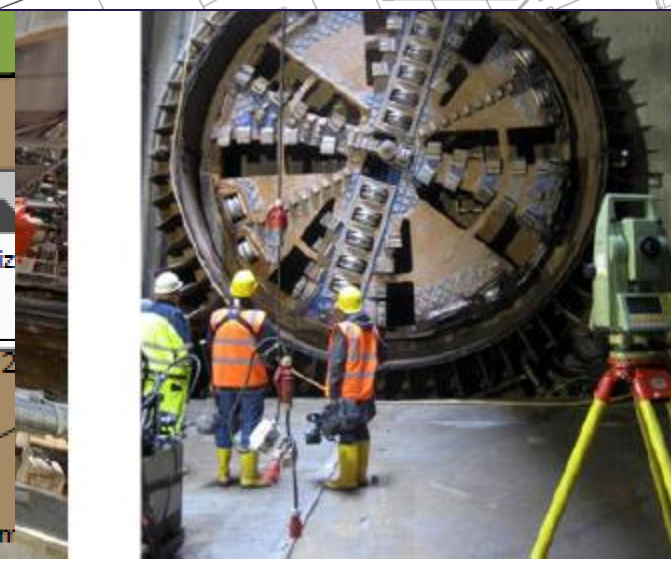
CIW (Goncharov et al): Single-shot broadband optical, and Coherent Anti-Stokes Raman spectroscopy.
CELIA (Batani, Dorchies et al): Hot plasma and High Pressure diagnostics & expertise.
CLPU-Salamanca (Roso et al): UHV chamber and metrology; short-pulse laser expertise.
DESY (von Zimmerman et al): Beamline 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

Surface building near SASE 2



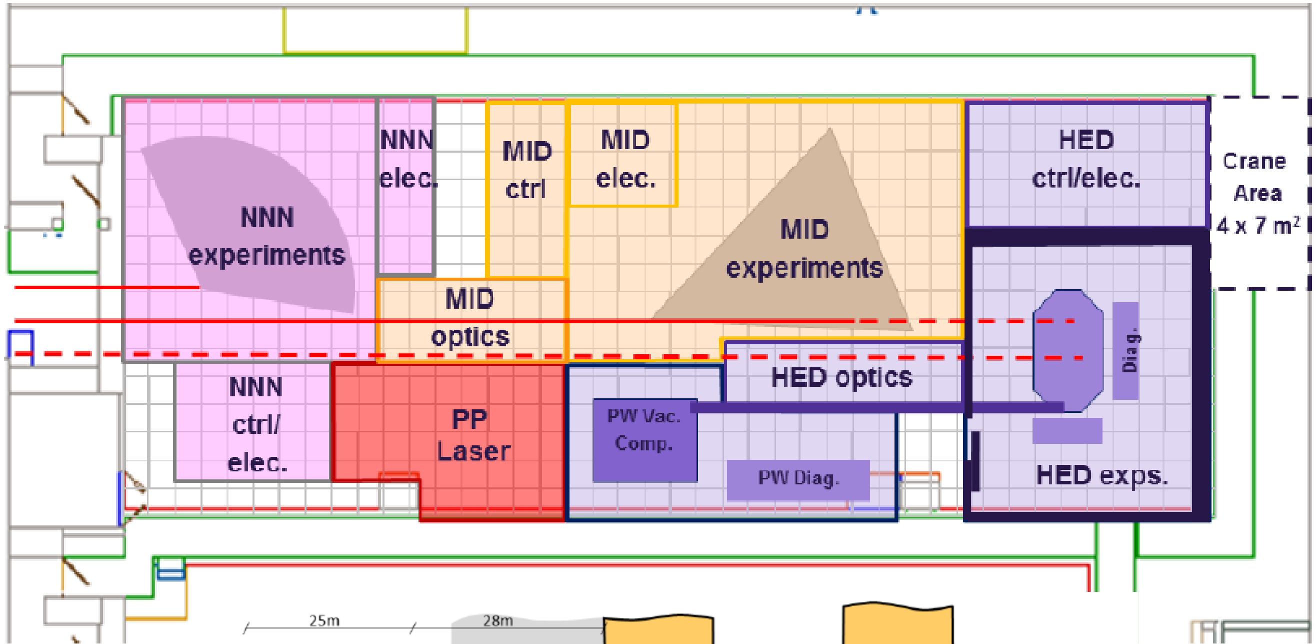


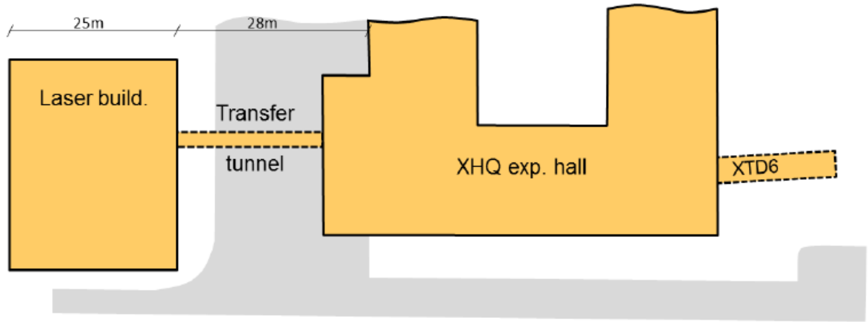


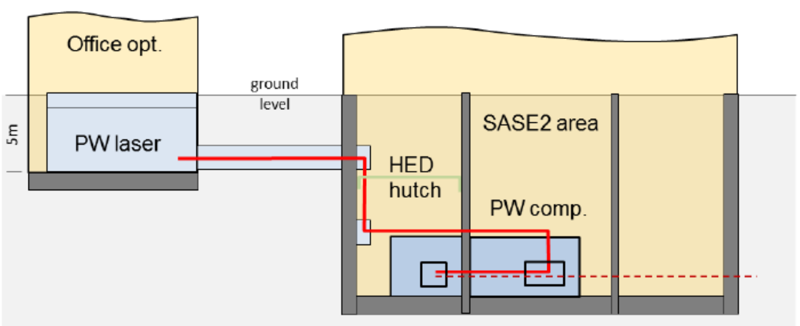
Thomas Tschentscher, European XFEL,
Hamburg, 13/11/2011

Helmholtz Beamline-XFEL

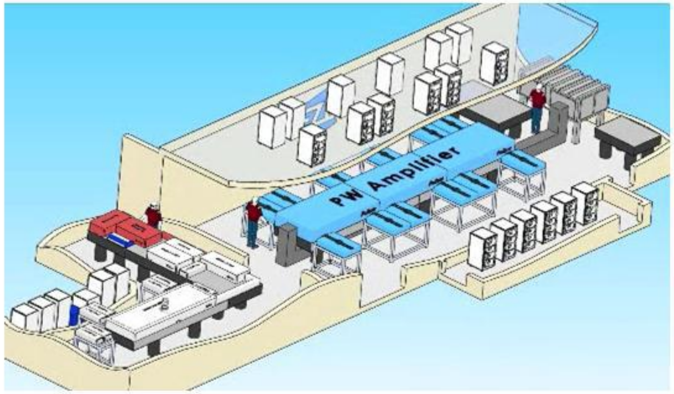
SASE2



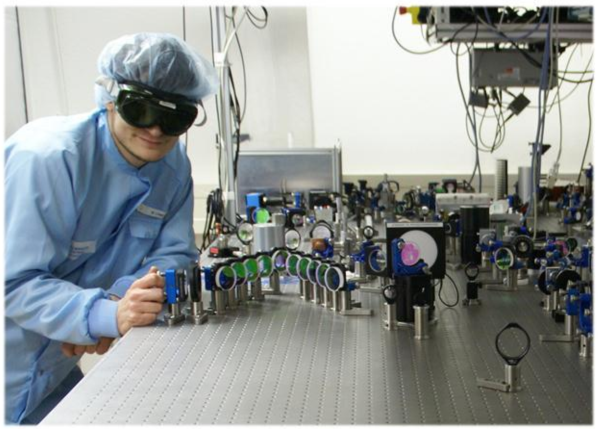


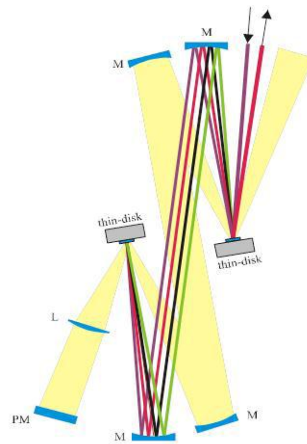


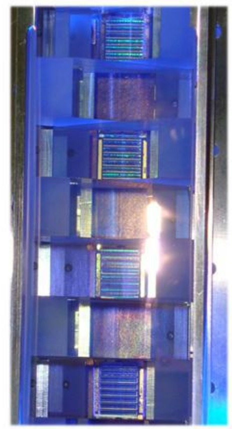
Helmholtz Beamline-XFEL: PW Laser Options



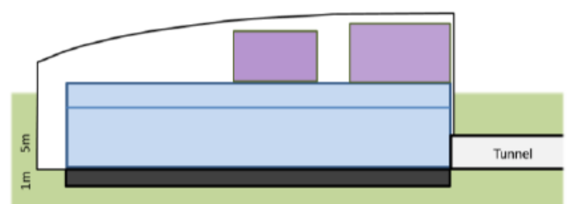
Ti:Sapph
30 J / 30 fs / 1 Hz
6 J / 30 fs / 10 Hz







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



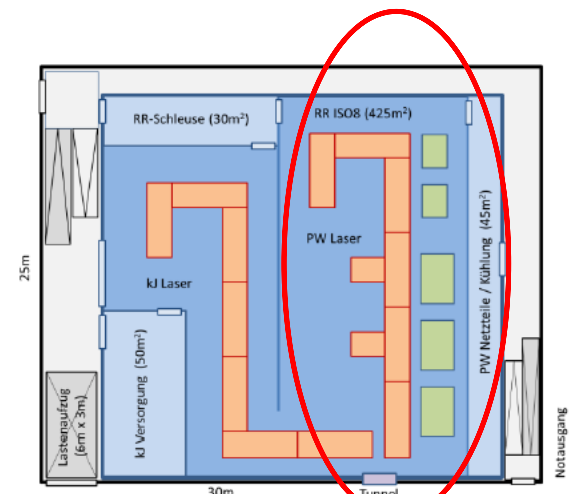
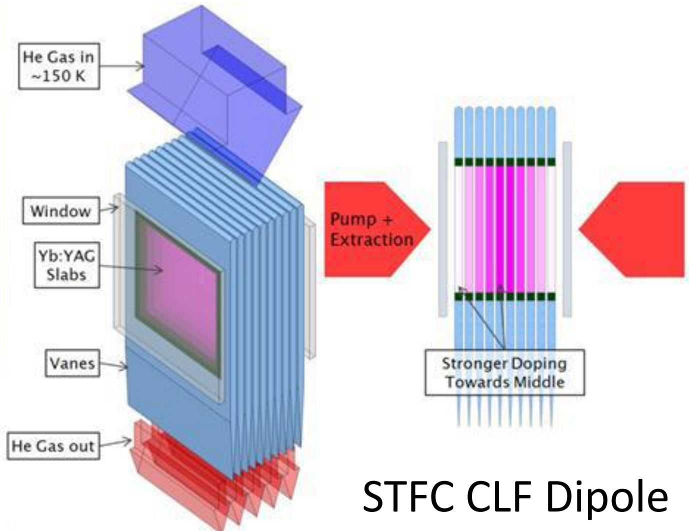
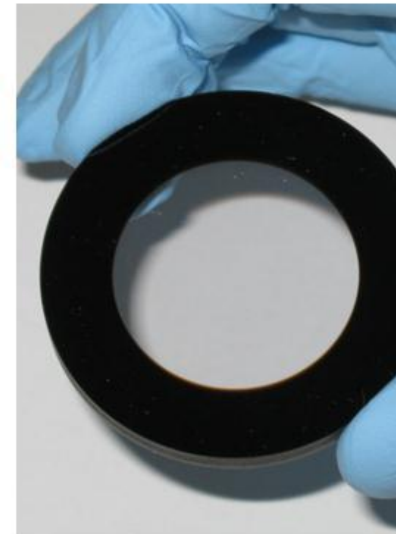


Fig. 9: Side view of the underground levels of the proposed laser building which does not yet incorporate additional office space in potential upper floors (left). Foot-print of the clean-room laser lab showing examples of PW and kJ laser table installations (right).

Helmholtz Beamline-XFEL: kJ-class Laser Options

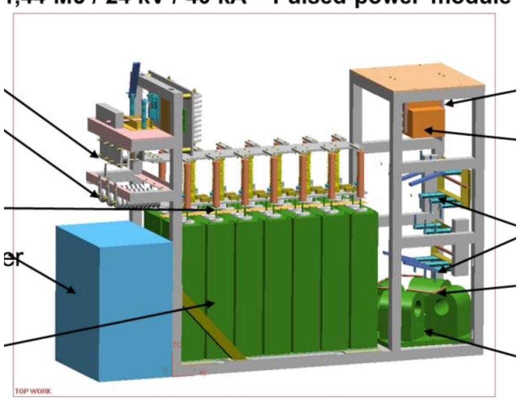


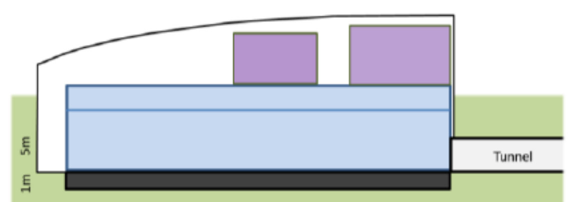


STFC CLF Dipole
10 J / 10 Hz

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

1,44 MJ / 24 kV / 40 kA – Pulsed-power module





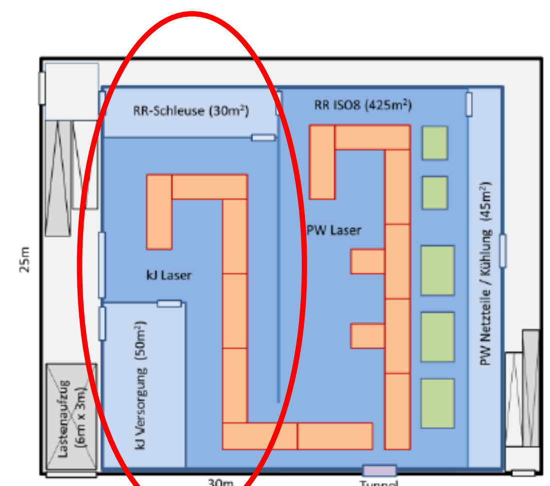
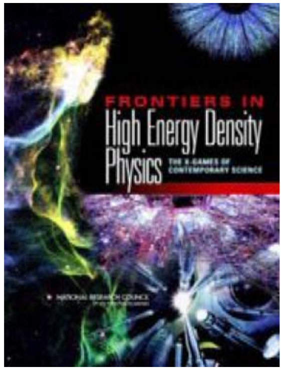
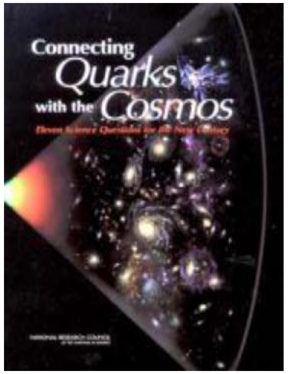


Fig. 9: Side view of the underground levels of the proposed laser building which does not yet incorporate additional office space in potential upper floors (left). Foot-print of the clean-room laser lab showing examples of PW and kJ laser table installations (right).

Background: Science using kJ and PW lasers

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





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

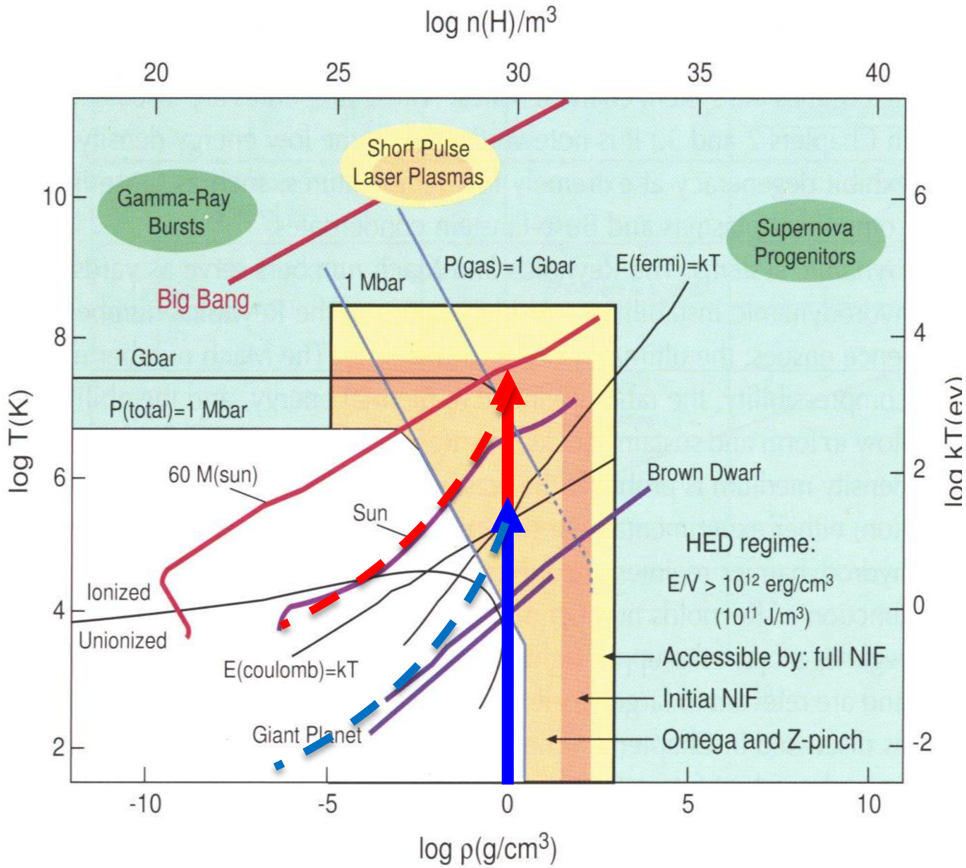
→ laser-drivers at 4th generation XFEL will be revolutionary

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

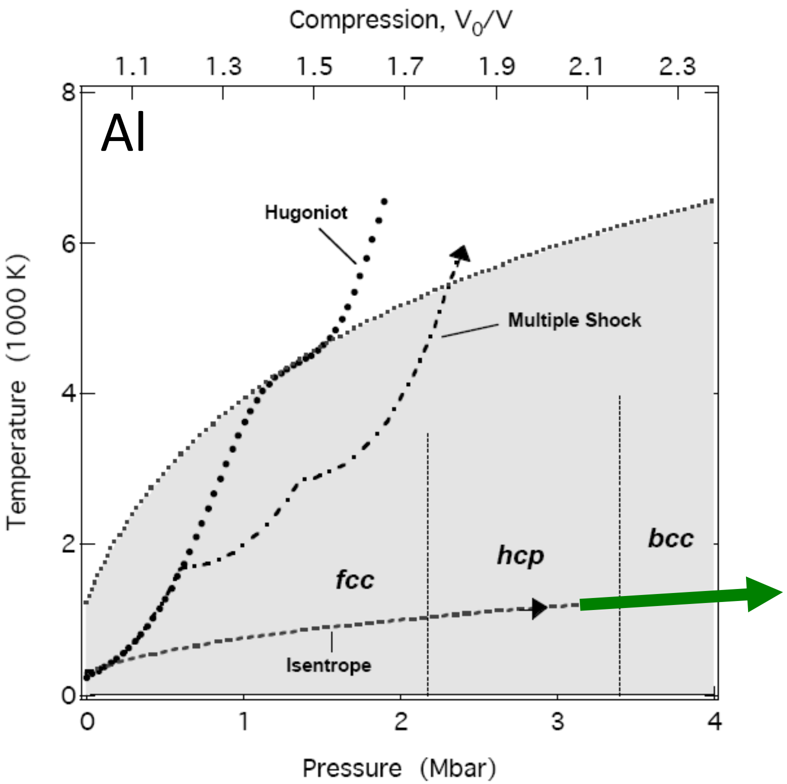
from "demonstration" → to "precision & systematic" exploration

Helmholtz Beamline-XFEL: extending HED Science at XFEL

Isochoric Heating



Compression



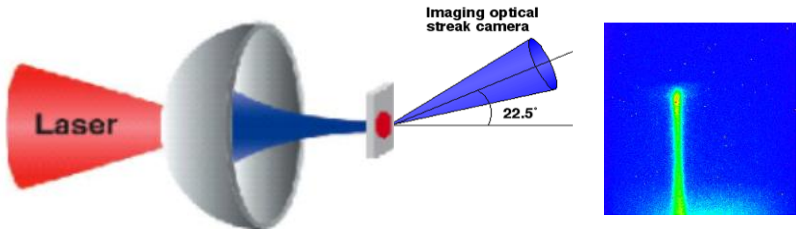
- Short-pulse laser-driven
- XFEL-driven

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

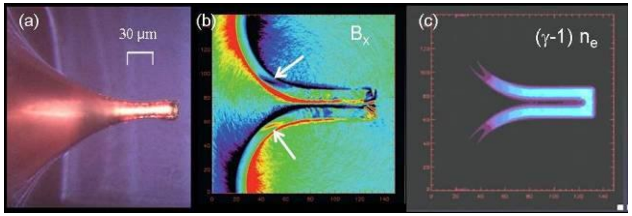
DRESDEN concept HZDR

Isochoric heating with ultra-intense short-pulse lasers

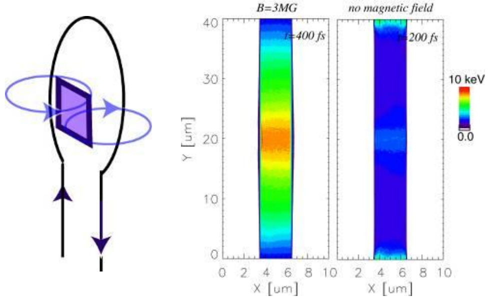
Isochoric heating with laser-accelerated protons
Patel *et al.*, Phys. Rev. Lett. **91**, 125004 (2003)



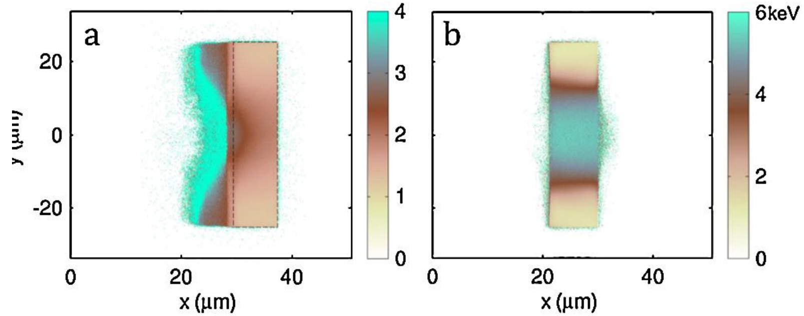
Self-generated magnetic confinement of hot electrons and enhanced heating
Rassuchine *et al.*, PRE **79**, 036408 (2009)



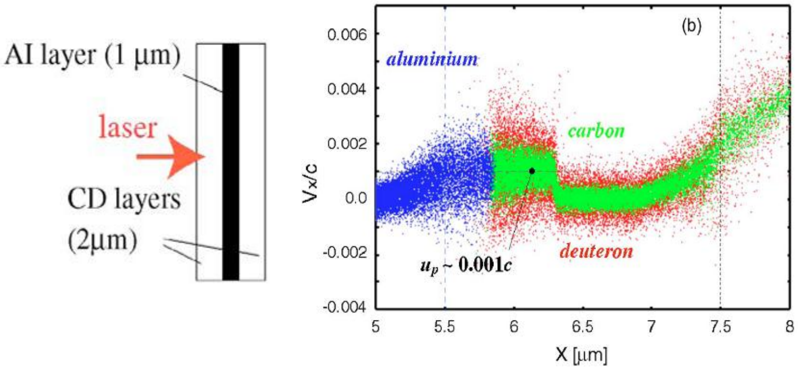
Pulsed external ~MG magnetic transport inhibition
Bakeman *et al.*, Megagauss XI (2007)
http://conferences.theiet.org/mg-xi/mgxi-final-v7.0.pdf



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



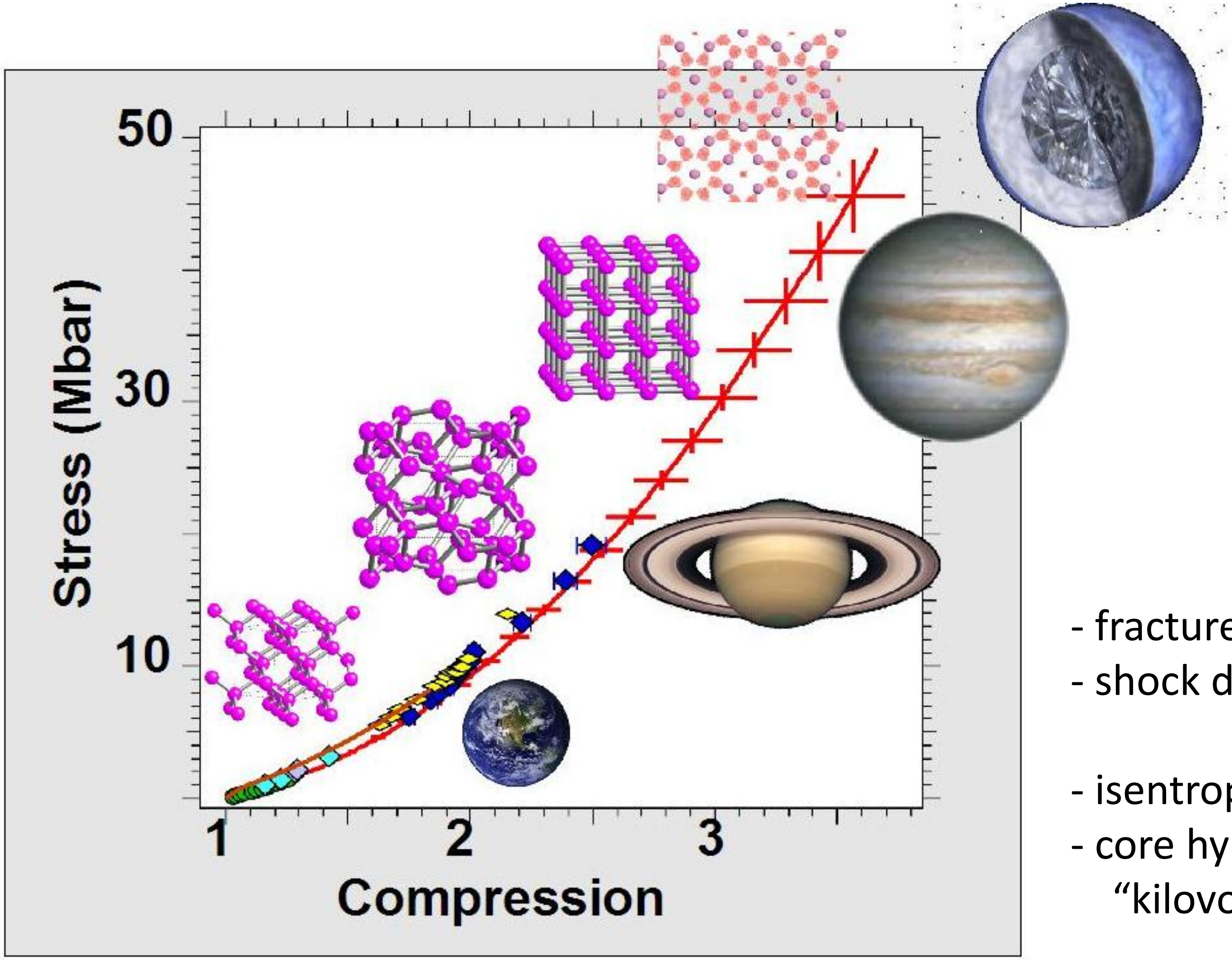
Interface shock heating in heterogenous targets
Sentoku *et al.*, Phys. Plasmas **14**, 122701 (2007)



→ 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"

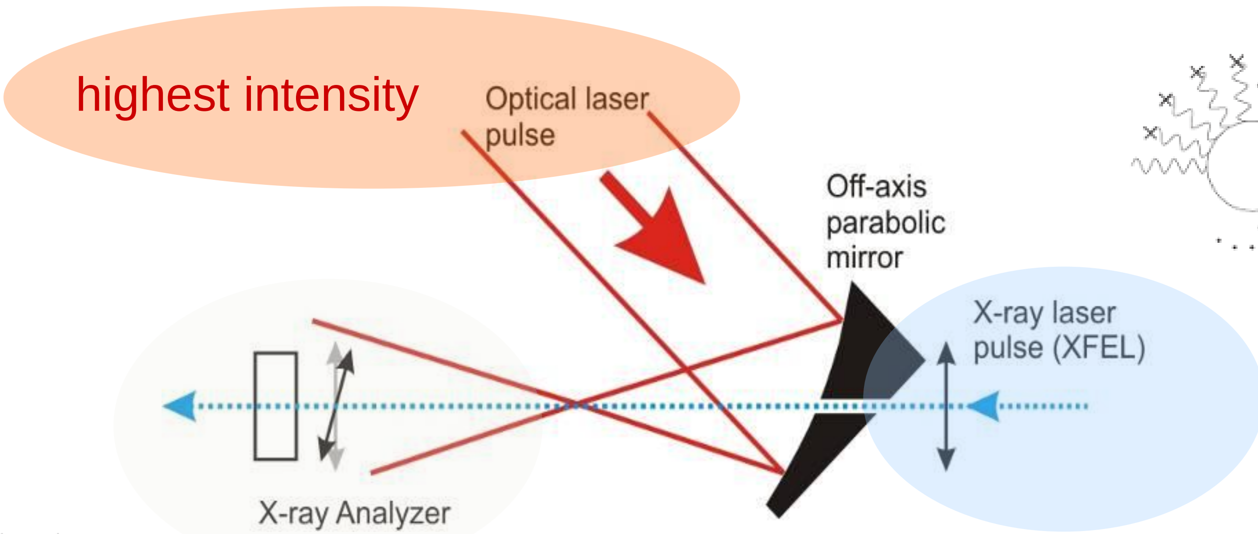
- "materials by design"

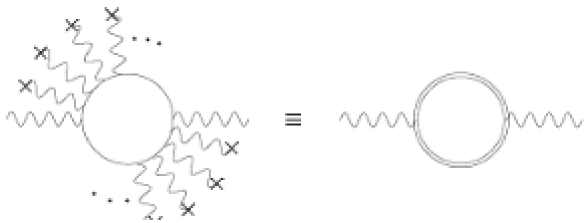
with Rostock, Oxford, DESY, Edinburgh, LLNL, LANL, LCLS, LULI, CEA, CELIA-Bordeaux, IOE-MUT

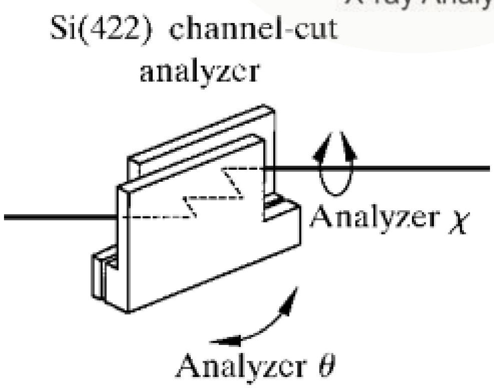
Courtesy G. Collins

E.g., Birefringence of QED Vacuum

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







at 15 keV, 10^{22} W/cm^2

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

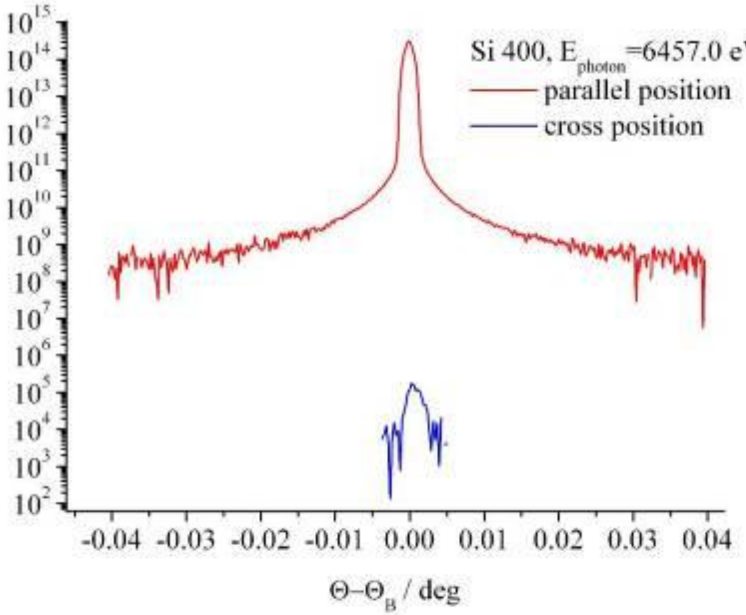
HZDR

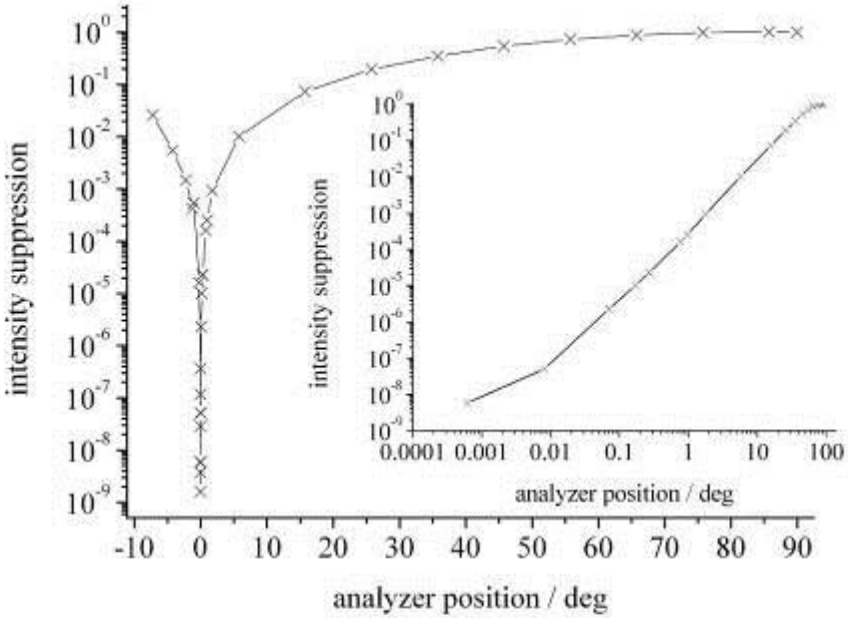
Realization – channel-cut Bragg crystal polarimetry

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

(5 x 10^{-10} polarization)

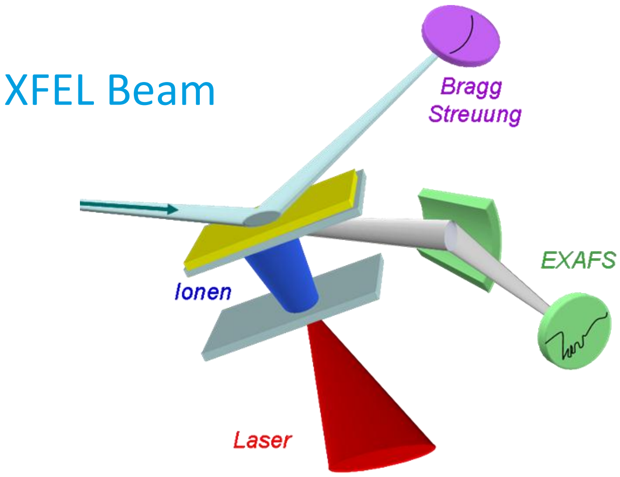
Channel cut Si 400 crystal





Dynamics of particle-induced damage

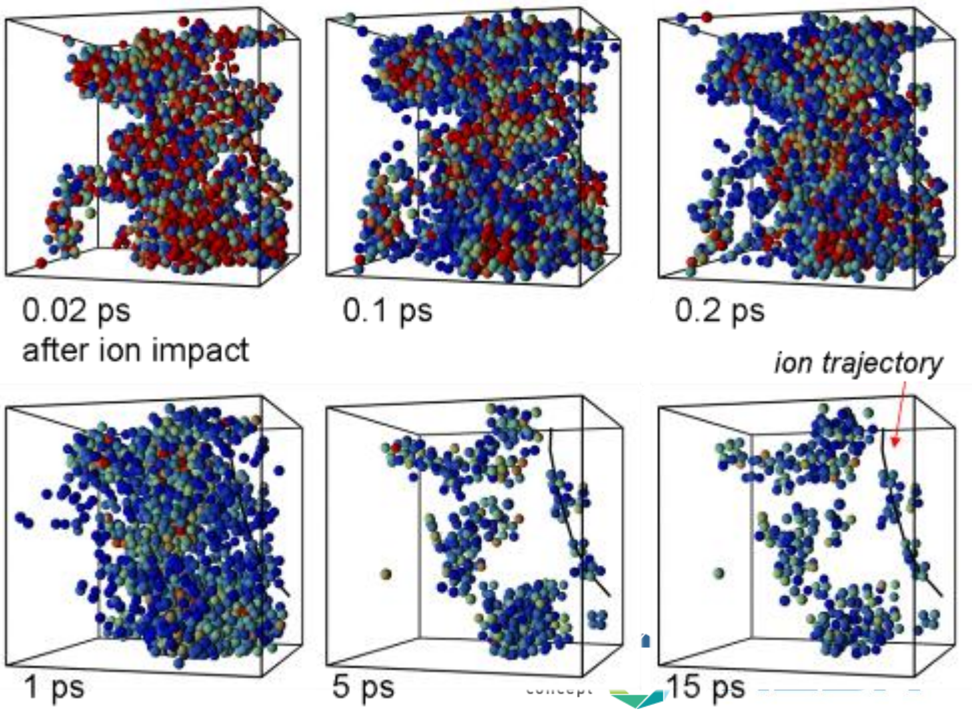
GOAL: Predictive understanding of ion-induced damage, by experimental bench-marking & validation of MD calculations of full dynamics



- **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

Helmholtz Beamline-XFEL: Ultra-Intense Laser Interactions

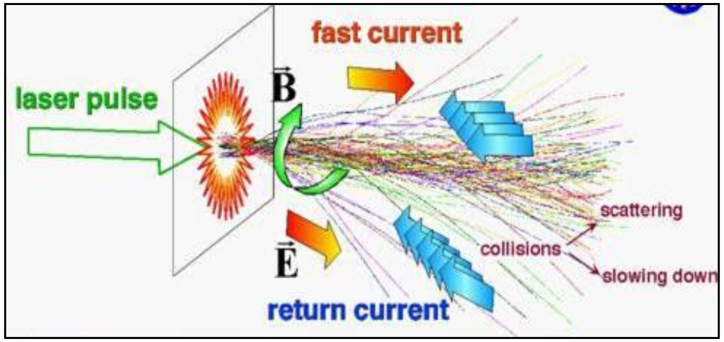
XFEL-quality probing inside of dense plasma (with time-resolved, brilliant, and fully coherent x-rays), will revolutionize our fundamental understanding of laser-matter interaction physics…

…and benefit Ultra-intense Laser and HED Plasma research worldwide, in many areas…

- Compact Accelerators
- Table-top light sources
- Radiation research in Oncology
- Fusion energy research
- Ultrafast science
- Warm Dense Matter & HEDP
- Material dynamics
- Laboratory Astrophysics

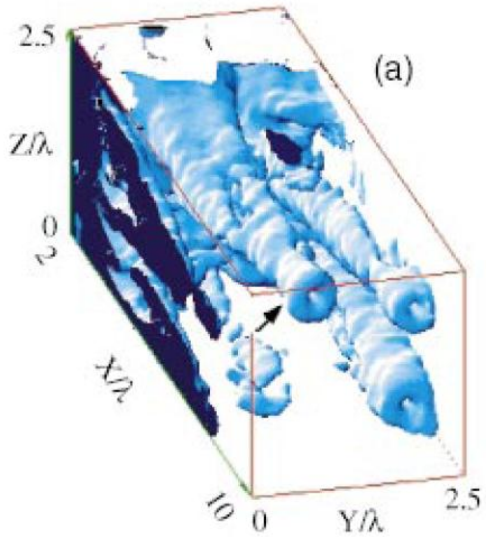
Ultra-Intense Laser-Matter Interactions – Key Challenges

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**



Essential Questions:

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

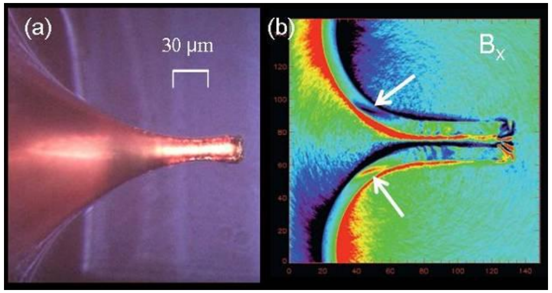
- Extreme transients & gradients
- Transition through cold-WDM-hot
- Extreme magnetizations

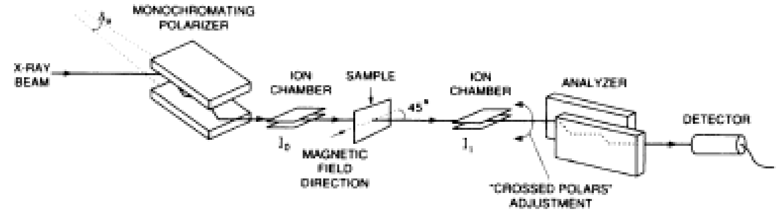
→ Ultrafast probing of B, Z*, j_e, T_e, inside solid-density plasma, time & space resolved

DRESDEN concept HZDR

Example 1. B-field imaging in solid-density plasma

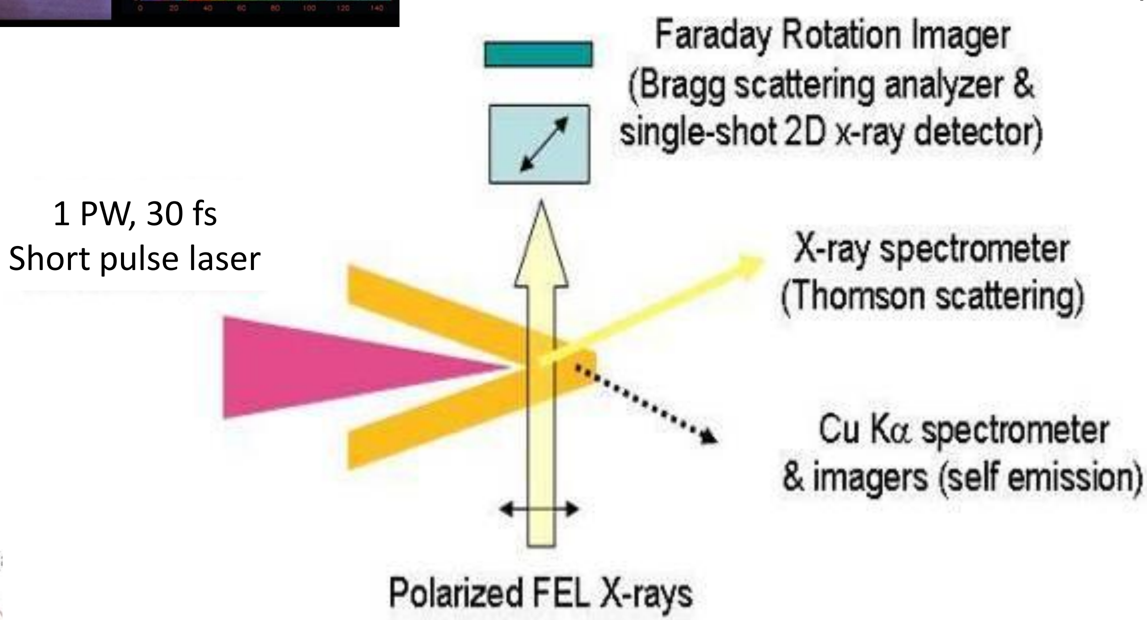
5000 Tesla *Quasi-static fields** → x-ray Faraday rotation imaging



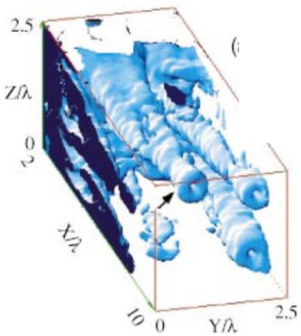


$$\Delta\varphi \approx K\lambda^2 \int n_e B_z dz$$

th K= 2.629×10^{-13} M.K.S. units.



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



**Apply also to filamentation...*

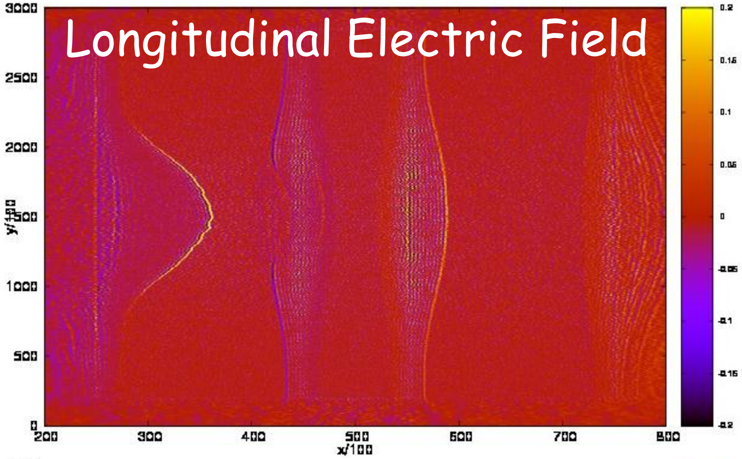
(self-seeding → potential for complementary x-ray interferometry)

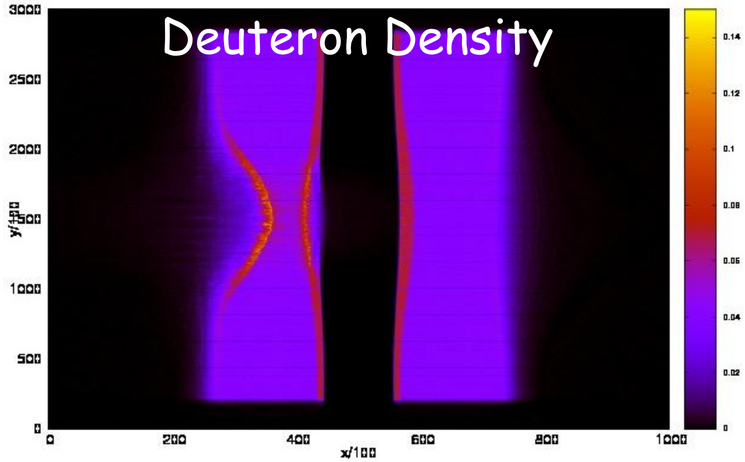
DRESDEN concept

HZDR

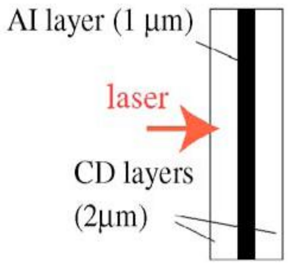
Example 2. Heating at interfaces inside solid-density targets*

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. 黄林根





$10^{21\text{-}18}$ W/cm^2
30 fs → few ps



EU-XFEL experiment:

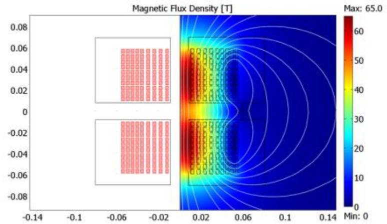
- CXDI → Image internal shock
- XPCS → Time-resolved disorder & melt
- X-ray Thomson → T_i, T_e, n_e (Z^*)
- XANES → Ionization state
- Self-emission:
  Kα imaging, streaked Kα spect. (~ps)

*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)

XMAS experiments at XFEL in high pulsed magnetic fields

HLD.

- XANES and XMCD experiments in pulsed magnetic fields allow unrivaled access to element-selective information on electronic band band structure, spin, and orbital magnetic contributions.



- At fields up to 50 Tesla, the latest challenges in solid-state physics may be targeted, and key experiments on the following novel and functional material classes will be feasible:

  - frustrated magnets, spin chains, and metal-organic framework compounds
  - magnetic high-temperature superconductors (e.g. iron pnictides)
  - mixed-valence systems
  - multiferroic compounds
  - heavy-fermion systems
  - exotic superconductors with non-phonon mediated Cooper-pairing
  - magnetically ordered superconductors
  - magnetic semiconductors
  - topological insulators
  - spin-ice compounds with magnetic-monopole excitations

Summary

Helmholtz Beamline at EU-XFEL will provide 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, or shot-on-demand
- from "demonstration" → to "precision & systematic" exploration

→ XFEL-quality x-ray probing will revolutionize Laser-Matter Physics

- brilliant, coherent, time/space-resolved x-ray probing of solid-density plasma

Thank you for your attention…

DRESDEN concept HZDR

Supplementary slides for XFEL SAC

- Uniqueness of EU-XFEL for the science of Helmholtz-Beamline
- Science & Technical requirements for a supplementary laser building
- Cross-disciplinary X-ray techniques
- Physics beyond 4 Mbar

Helmholtz Beamline-XFEL: Science & Facility

- Science → making <u>unique</u> use of XFEL x-ray capabilities

  - Single-pulse → intensity, pulse width, brightness, coherence, polarization
    (also available at other X-FEL's)

  - Bunch train → <50 fs synch., multi-user operation, 600 µs macro-pulse
    (unique to European XFEL)

  → Best x-fel worldwide for low-rep-rate & shot-on-demand experiments
  → Best x-fel worldwide for complex, multi-pump/probe, ultrafast phenomena
  → Only hard x-ray source worldwide for research with *highest* B-fields

  Unique opportunity worldwide, for integrating high-power-laser & high-field-magnet experiments with hard x-ray FEL

- User Facility (!) – reliable routine multi-user operation (few-shift expts)
  - Established laser technologies
  - Conservative operation (e.g., at <80% of damage threshold)
  - 2015 start, flexibility for upgrades

Uniqueness of European XFEL / Pusler Requirements

HLD.

EU-XFEL uniqueness:

- XFEL micro-pulse bunch train is unique among hard x-ray sources: provides sufficient fluence for X-ray Magnetic Absorption & Scattering experiments up to 50 T (~ms pulses)

Sample properties determine magnet pulse-length requirements

MJ-class pulser is required for small dB/dt:

- Superconductors
- Metals & semiconductors
- Very low temperature samples

MJ-class pulser requires supplemental space → laser bldg

Laser System Considerations

PW-class required for highest intensity >10^{21} W/cm^2
- absolute requirement for vacuum birefringence
- ultra-intense laser-matter interaction, ultrafast pulses

Several-10 J pulse energy required for:
- heating & transport experiments in solid-density plasma
- quasi-static magnetic field generation
- fusion-relevant research

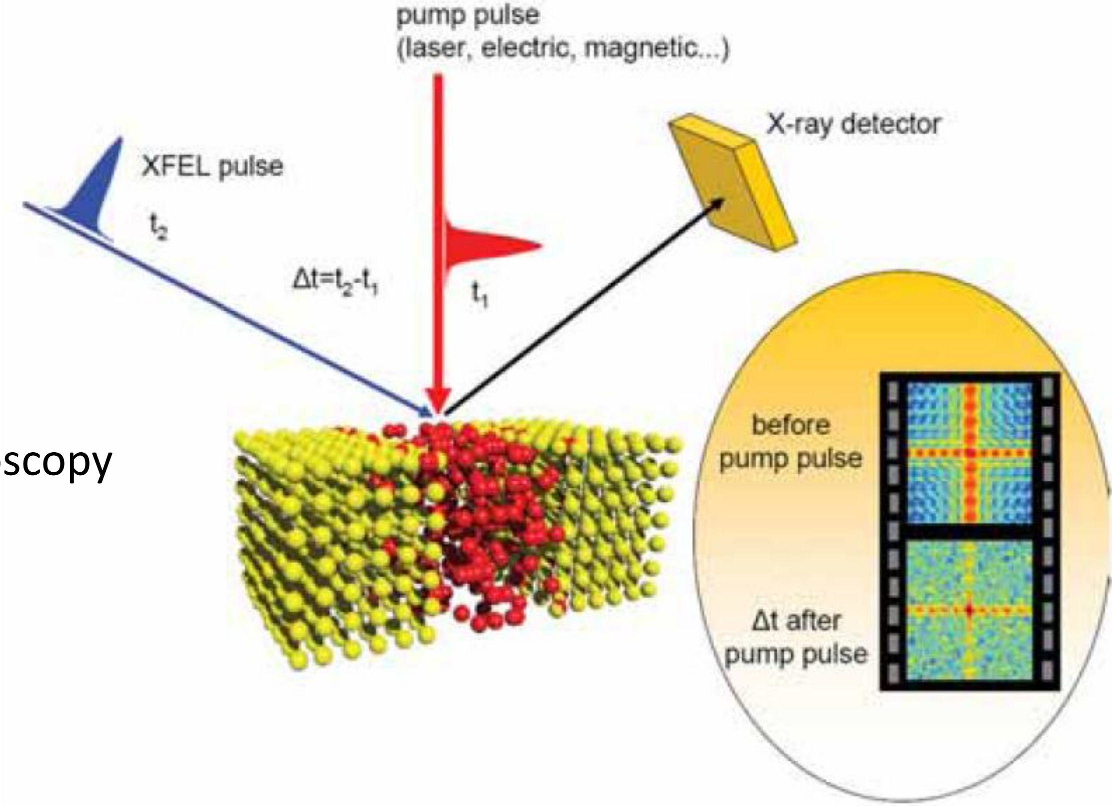
30 fs –class laser required for ultra-fast phenomena:
- laser-solid interaction physics

High-pulse energy (100+ J) required for high pressures

→ High-stability laser-laboratory space is required to extend beyond 100 TW, and/or also provide for high-energy driver

Important Challenge – Advancing hard X-ray Techniques

→ **Adapting techniques from: Synchrotron-, Laser-, FEL-, & Ultrafast-science communities**



Example: XPCS
X-ray Photon Correlation Spectroscopy

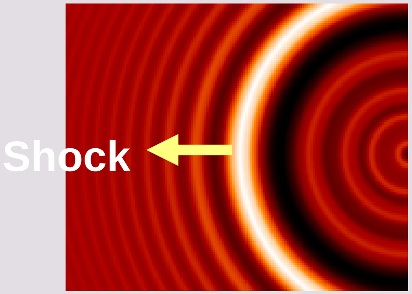
- Single-pulse x-ray Split & Delay
- Self-seeding (full coherence)

→ X-ray Interferometry, Holography
→ Multi-beam Tomography, Faraday Rotation imaging
→ SAXS, WAXS, CXDI, X-FR, ….
→ XANES, XRTS, RIXS, ….

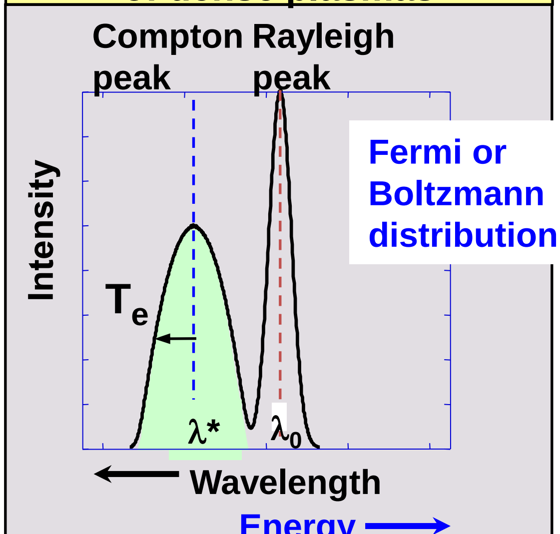
→ ***Critical for detailed Science Case and CDR preparation***

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

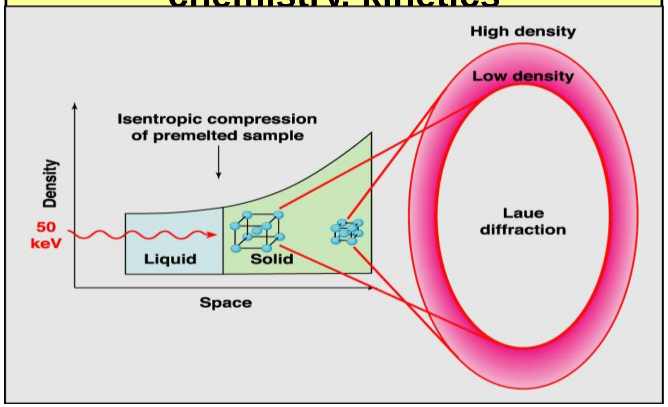
Diffractive imaging



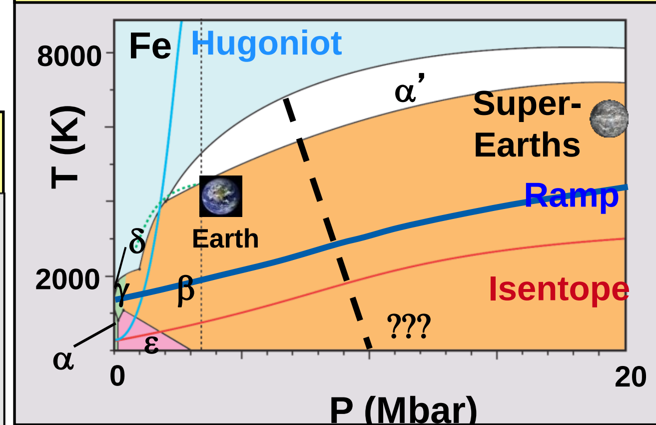
Compton scattering Te,Z,ne,collision time of dense plasmas



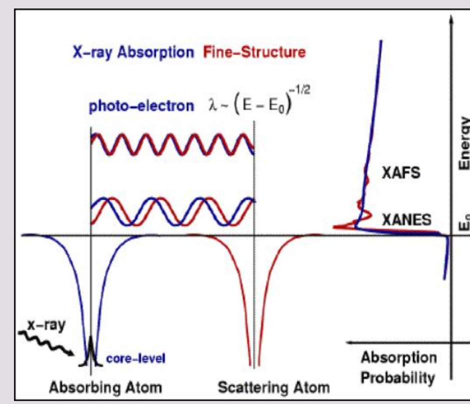
X-ray scattering => structure, chemistry, kinetics



Material phases, thermodyn. states

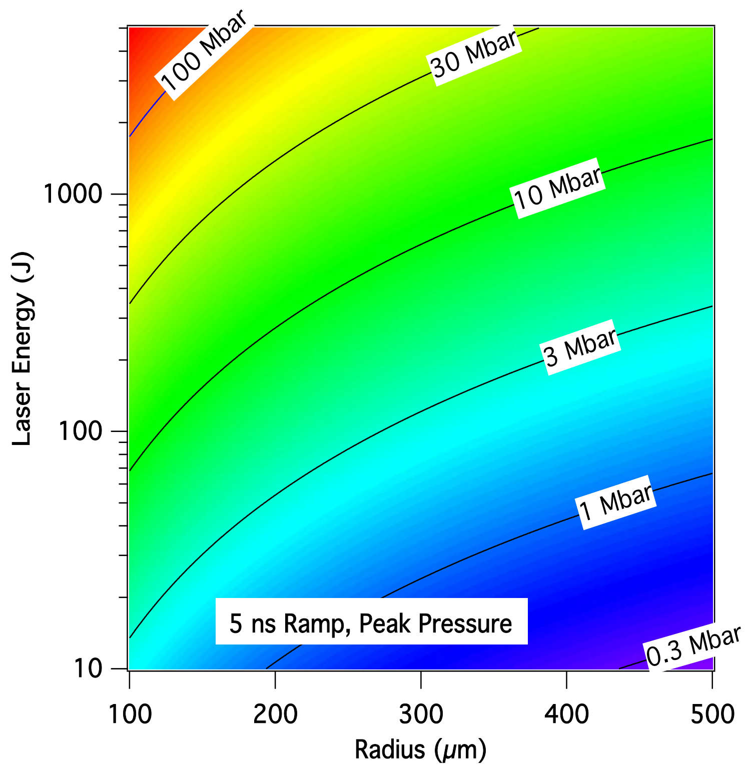


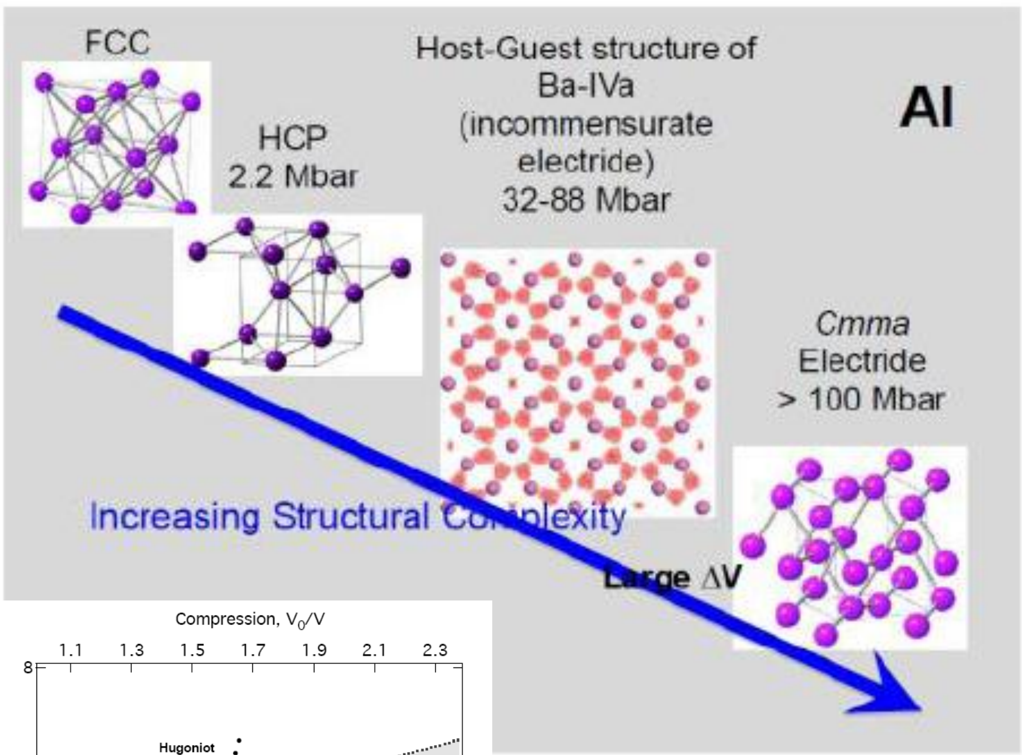
X-ray absorption for Melt, Chemistry

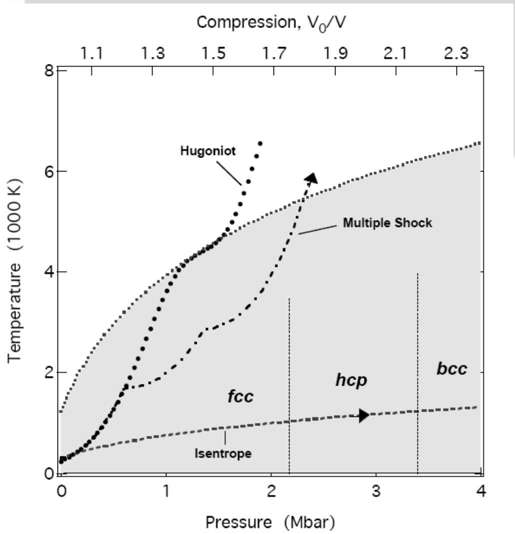


Courtesy G. Collins

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







Courtesy H-P Liermann