ESRF towards dynamic compression

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The European Synchrotron | ESRF

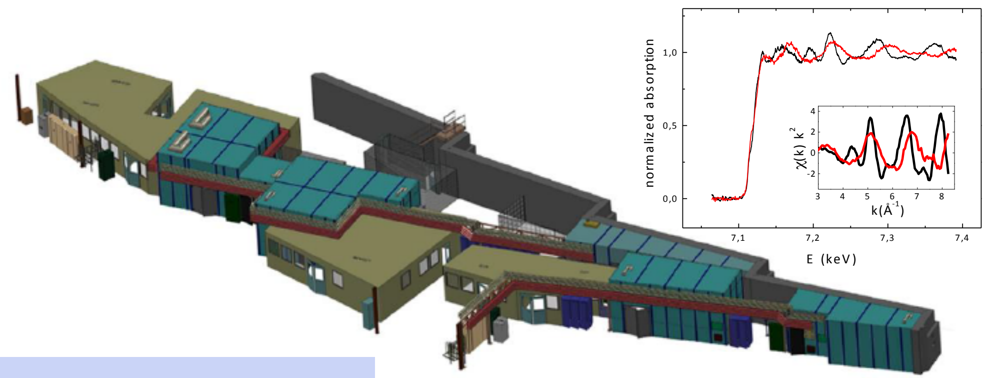
OUTLINE

- The HPLF project
- First dynamic compression experiments at the ESRF
- HPLF-I Technical design
- Future perspectives

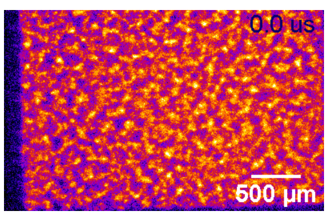
HIGH POWER LASER FACILITY PROJECT

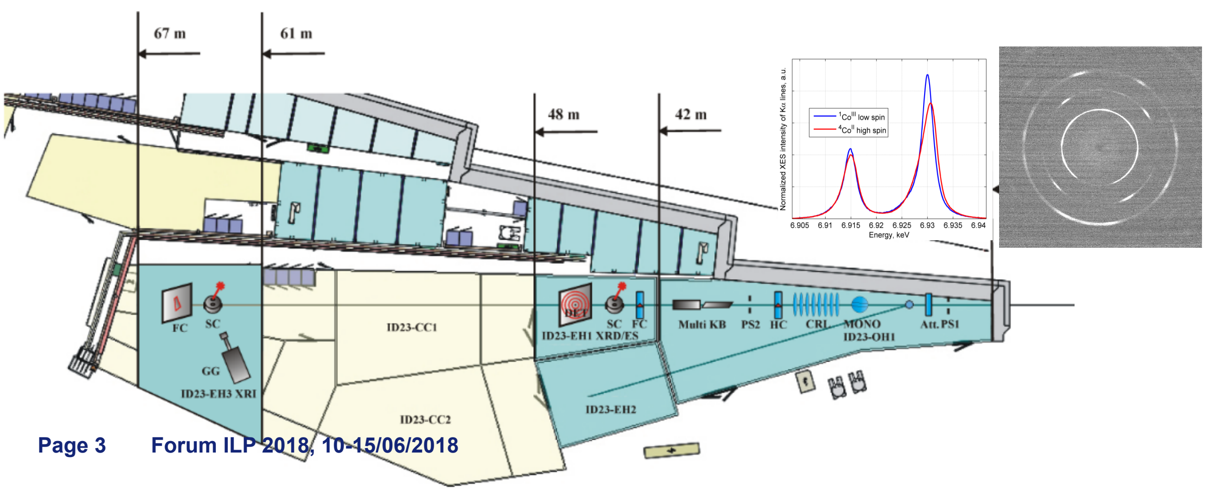
Coupling of a ns powerful laser to synchrotron XAS, XDR, XRI and XES

HPLF-0 (2014-2018) :
Technical project evaluation
Single X-ray pulse XRD/XRI/XAS
Scientific project evaluation
Workshops and Conceptual Design



HPLF-I (2018-2021) :
installation of a ~100J laser and coupling ti the ED-XAS beamline ID24;





HPLF-II (from 2023):
extension of the facility to offer additional X-ray diagnostics: XRD, XRI, XES as part of the Extremely Brilliant Source (EBS) upgrade. An upgrade of the laser power to 200 J, is also envisaged.

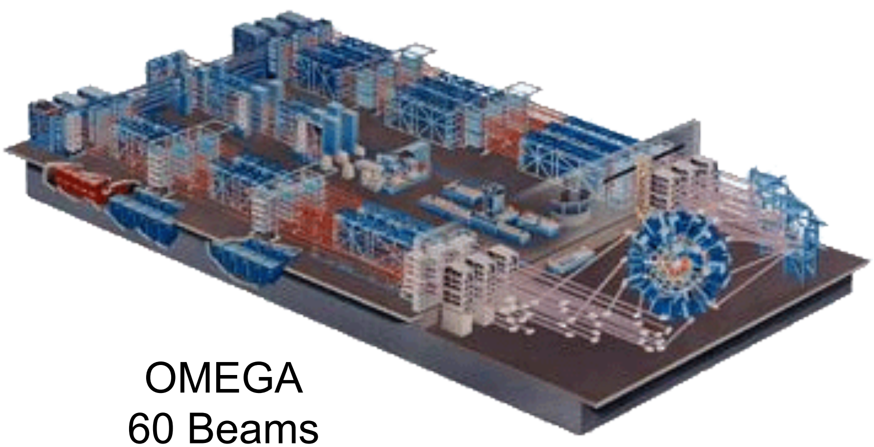
A NEW STRATEGY

From very big to very small

- ❑ minimize the experimental setup (laser + target) to reduce the energy needed to reach extreme states

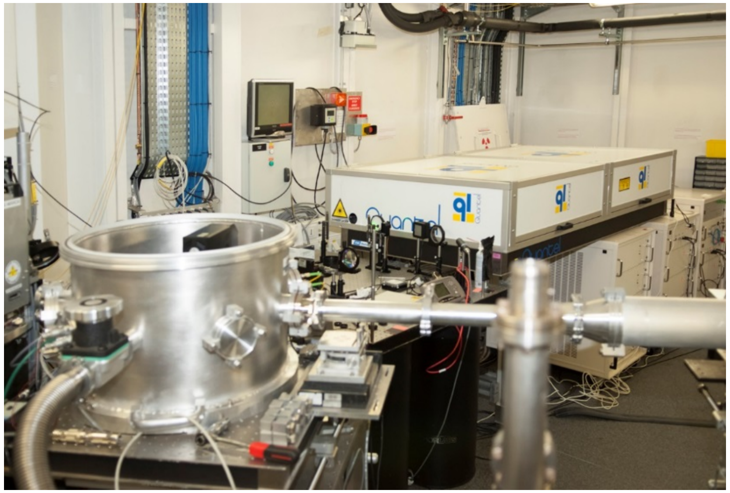
- ❑ install a compact powerful and focusing laser at a high brilliance X-ray facility

Few KJ lasers on mm targets



OMEGA
60 Beams
40 KJ

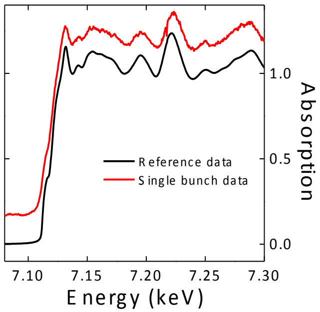
few 10 J lasers on 100 µm targets

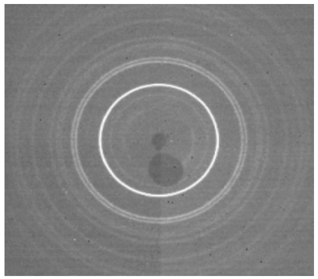


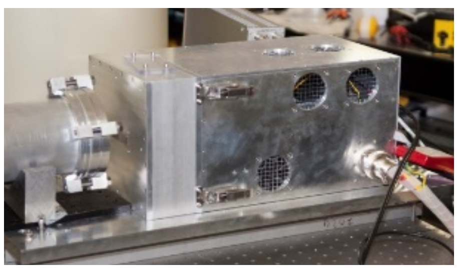
GCLT 40J

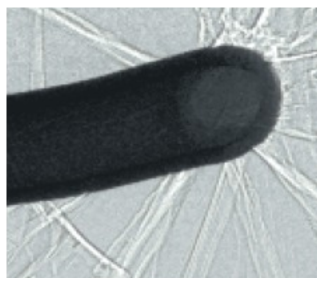
PROJECT HISTORY: FIRST DYNAMIC EXPERIMENTS

2013 single bunch

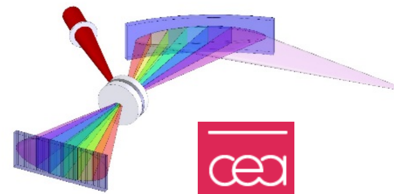


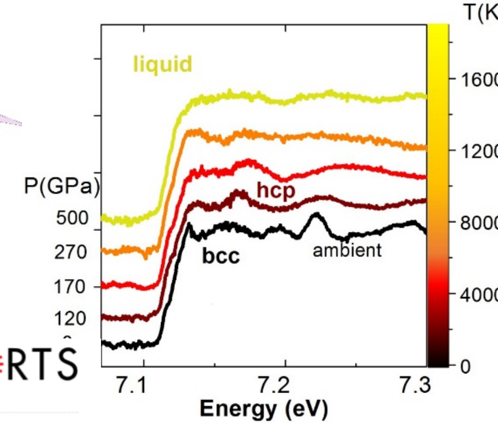






May 2014: first laser shock experiment at ID24 on Fe





SCIENTIFIC REPORTS

OPEN

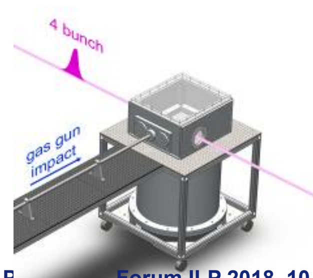
Probing local and electronic structure in Warm Dense Matter: single pulse synchrotron x-ray absorption spectroscopy on shocked Fe

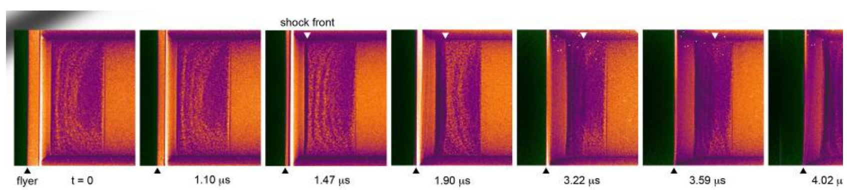
Received: 05 October 2015
Accepted: 28 April 2016
Published: 01 June 2016

Raffaella Torchio[1,2], Florent Occelli[1], Olivier Mathon[2], Arnaud Sollier[1], Emilien Lescoute[1], Laurent Videau[1], Tommaso Vinci[3,4], Alessandra Benuzzi-Mounaix[3,4], Jon Headspith[5], William Helsby[5], Simon Bland[6], Daniel Eakins[5,6], David Chapman[6], Sakura Pascarelli[2] & Paul Loubeyre[1]

Sept 2015: first gus gun exp @ ID19

Imperial College London





SCIENTIFIC REPORTS

OPEN

Probing the early stages of shock-induced chondritic meteorite formation at the mesoscale

Received: 28 November 2016
Accepted: 20 February 2017

Michael E. Rutherford[1], David J. Chapman[1], James G. Derrick[2], Jack R. W. Patten[1], Philip A. Bland[3], Alexander Rack[4], Gareth S. Collins[2] & Daniel E. Eakins[1]

HIGH POWER LASER FACILITY AT ESRF: SCIENCE CASE

Workshop on Studies of Dynamically Compressed Matter with X-rays

Monday 16 and Tuesday 17 February 2015

Venue: ILL Chadwick Amphitheatre

DyCoMaX

march 2017

march 2016

many of the science cases call for the development of dynamic compression at ESRF and require the use of high power lasers

Extreme conditions for geophysics and planetary science

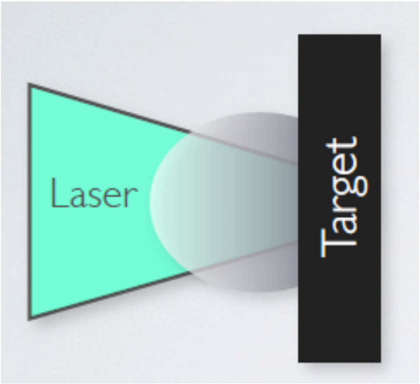
extra solar planets, warm dense matter

Dynamic behavior of matter and materials under high strain rates

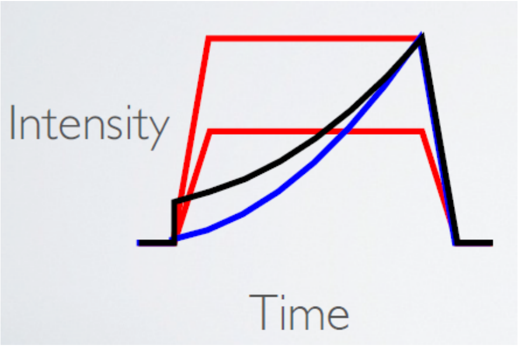
impacts, spallation, materials synthesis, plasticity, phase transitions kinetics, nucleation…

DYNAMIC COMPRESSION: LASER SHOCK AND RAMP EXPERIMENTS

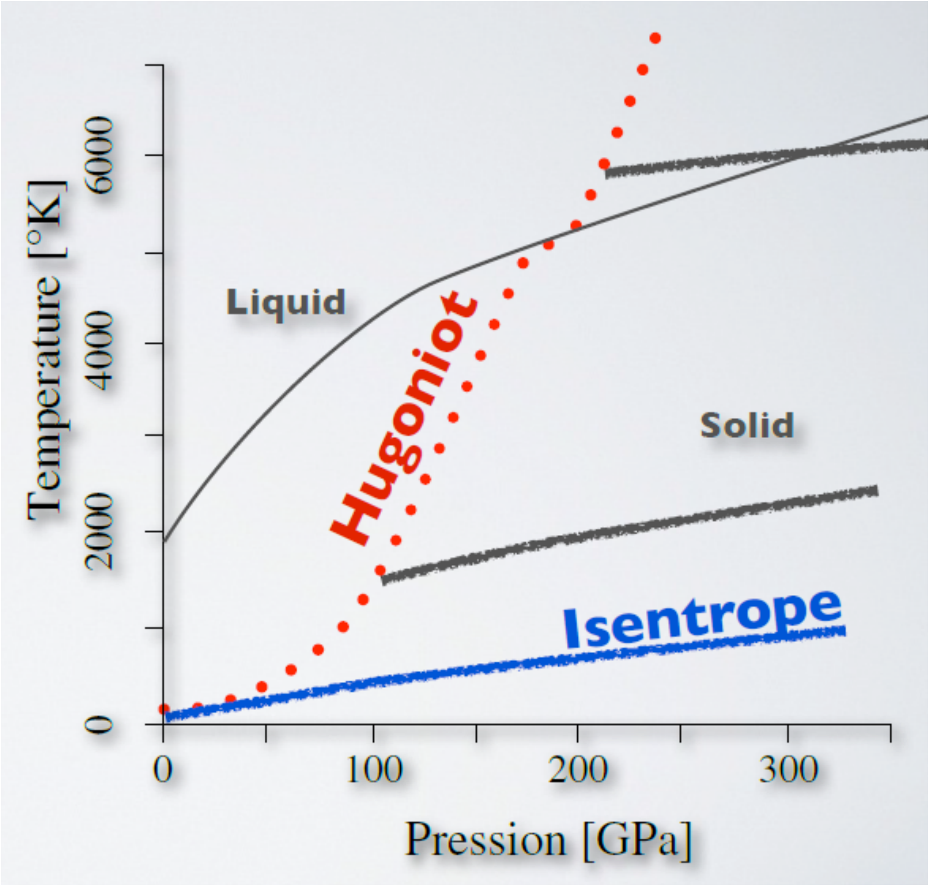
laser ablation technique



laser temporal profile



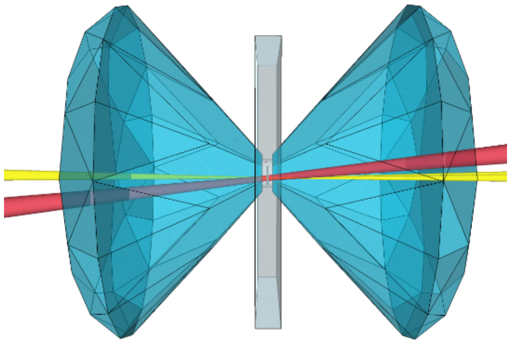
shock or ramp compression



synchrotron temporal resolution: 100 ps

SCIENTIFIC COMMUNITY

static high pressure community



dynamic high pressure community

EUCALL

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 654220

ACO-CHOCOLAS

Matériaux sous Hautes Vitesses de Déformation

Groupe de recherche CNRS

13 laboratories working on laser plasmas, shock wave physics, materials and applications

HPLF PROJECT - PHASE I TIMELINE

2016 - 2017: Phase I (2018-2021) approved
CFT awarded to

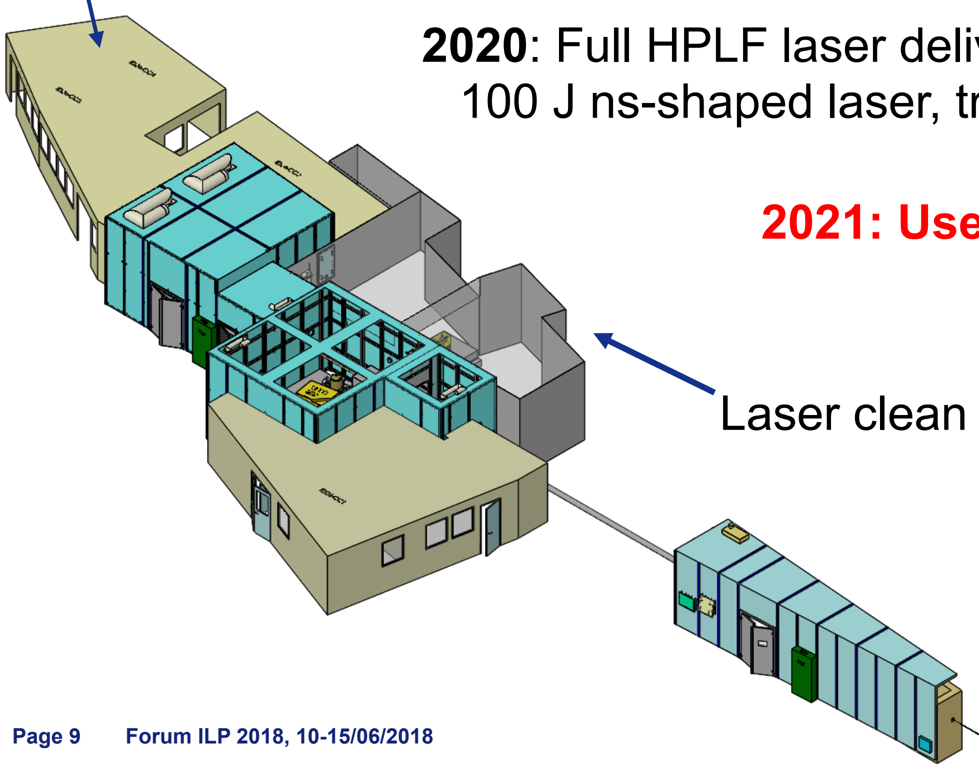
2018: Delivery and commissioning of the laser front end
experiments 2018

15J, 10ns
40-200 GPa

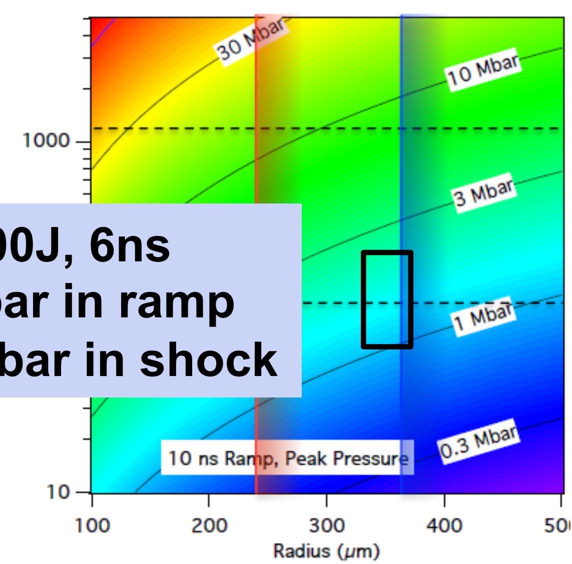
2019: EBS upgrade - Infrastructure realization
ID24 upgrade for EBS

2020: Full HPLF laser delivery, ID24 re-commissioning
100 J ns-shaped laser, transport, interaction chamber, diagnostics

2021: User operation



Laser clean room



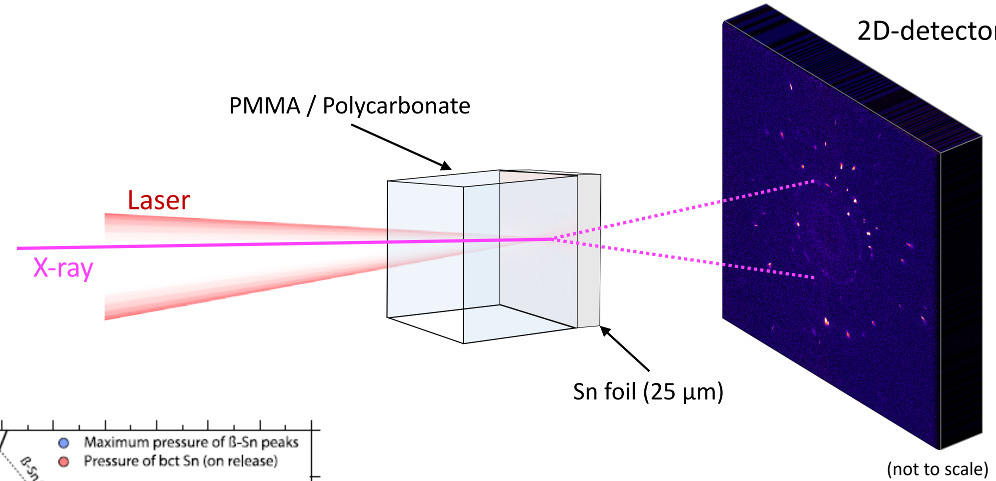
100J, 6ns
2 Mbar in ramp
5-10 Mbar in shock

First laser shock experiment at the ESRF

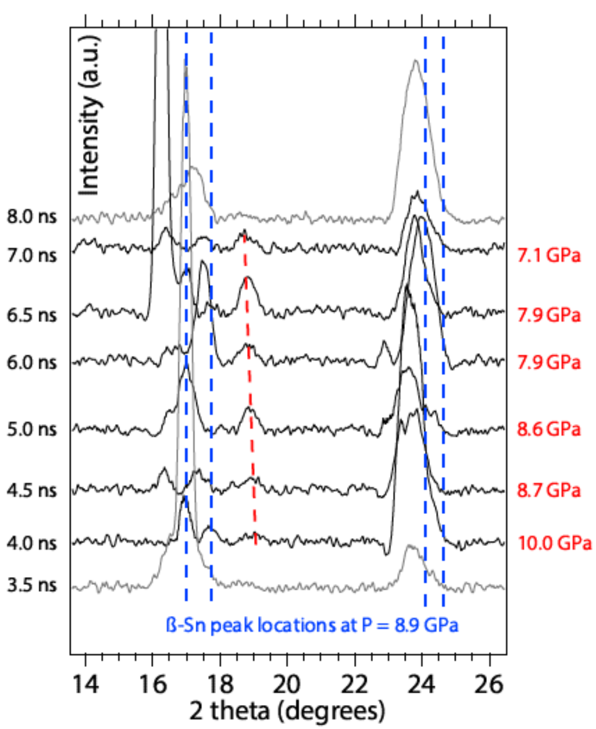
XRD XRI XAS

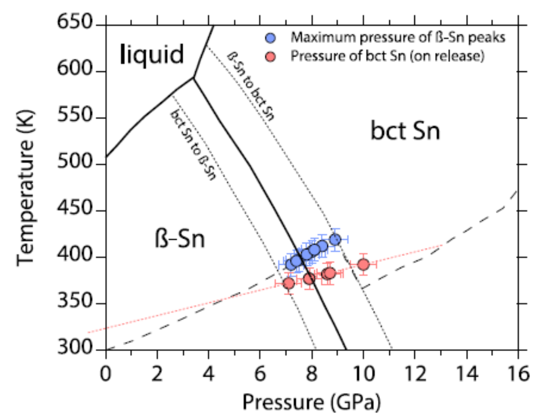
ID09 - DIFFRACTION AND DYNAMIC COMPRESSION

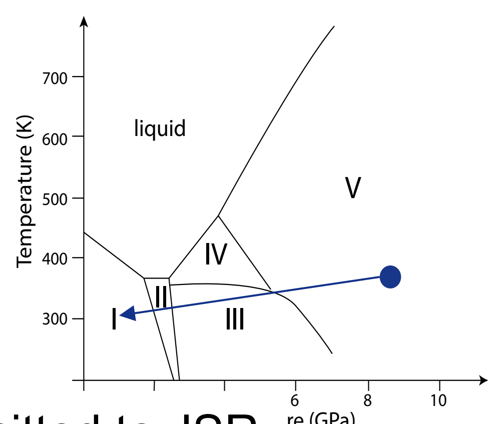
Single x-ray bunch 100 ps
Laser, 250mJ max, Ø250μm

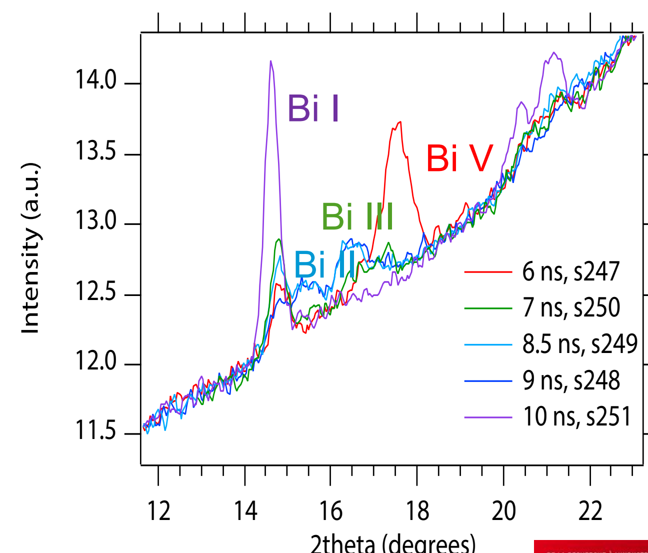


Shock compressed Bi and Sn









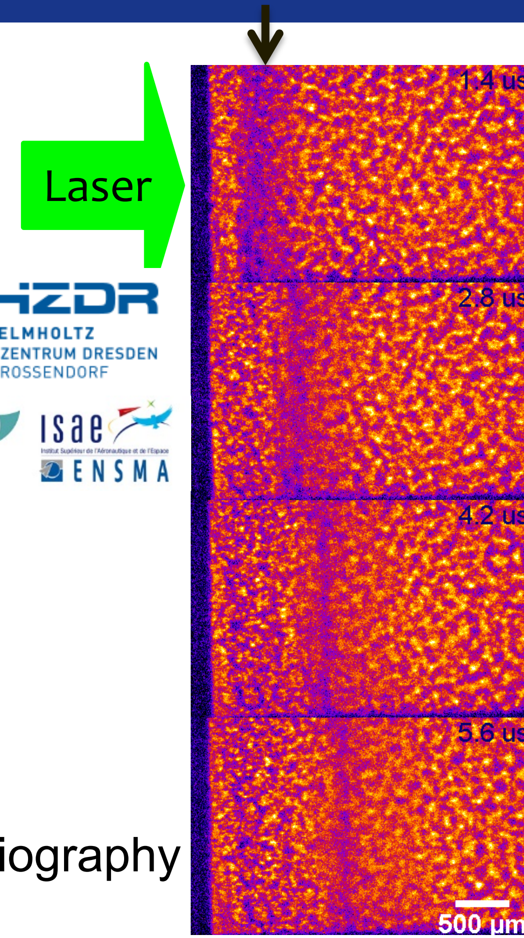
R. Briggs, R.Torchio et al., submitted to JSR

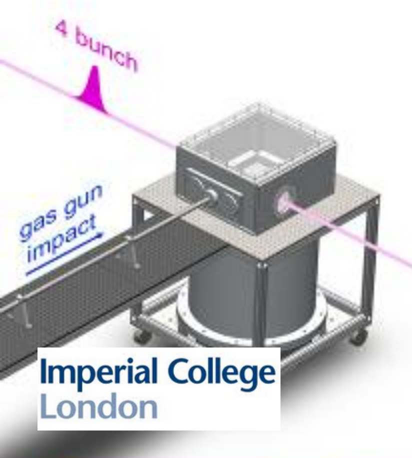
ID19 - IMAGING AND DYNAMIC COMPRESSION

Laser-induced compression of a polymer foam:
elastic compression, compaction, pore collapse, fracture, and fragmentation

- Laser shock, 6J @ 532nm, 10 ns FWHM
- Single bunch 100 ps phase contrast imaging
- HPV-X2 Shimadzu camera

Olbinado et al., J. Phys. D: Appl. Phys.,(2018)





SCIENTIFIC REPORTS

OPEN **Probing the early stages of shock-induced chondritic meteorite formation at the mesoscale**

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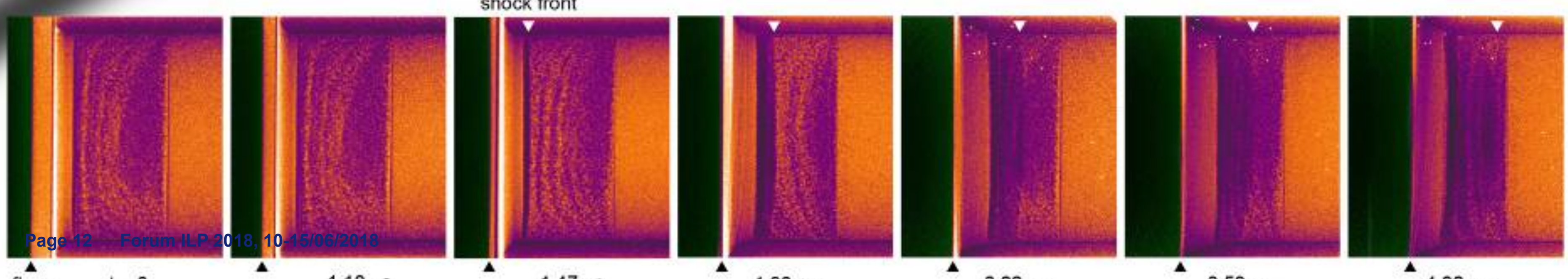
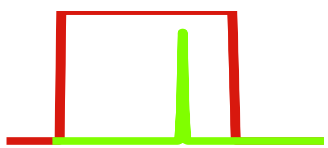
- Single bunch 100 ps phase contrast radiography
- Gas gun impact 600 m/s
- PI-MAX4:1024i Princeton ICCD



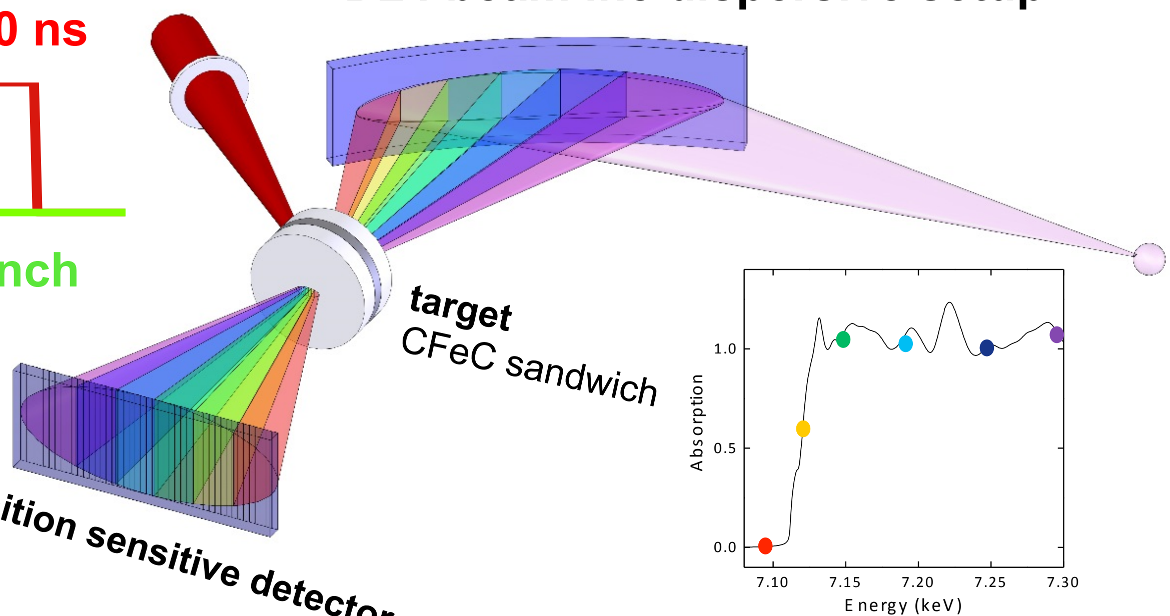
Laser shocked iron

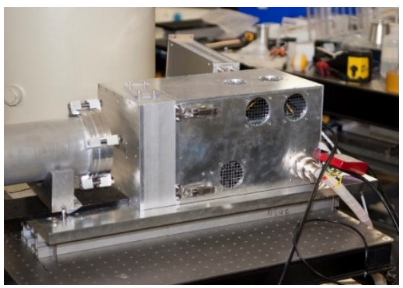
Laser
35 J 10 ns



X-ray bunch
100 ps

ID24 beamline dispersive setup

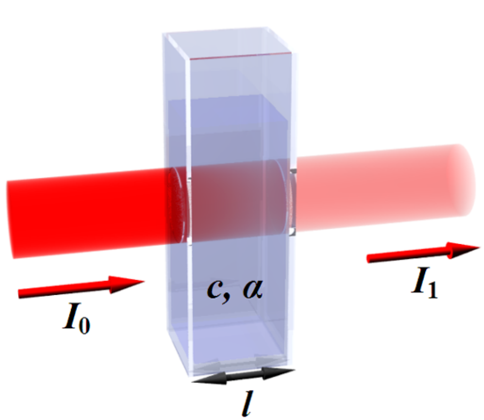




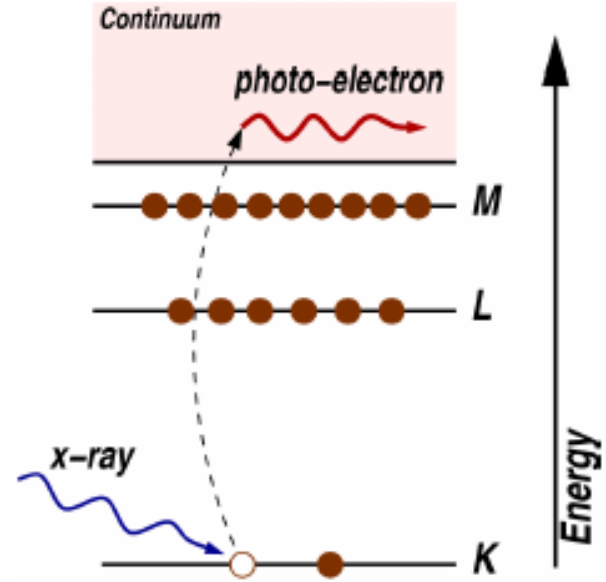
int. time150 ns
1 scan every 2.8 μs

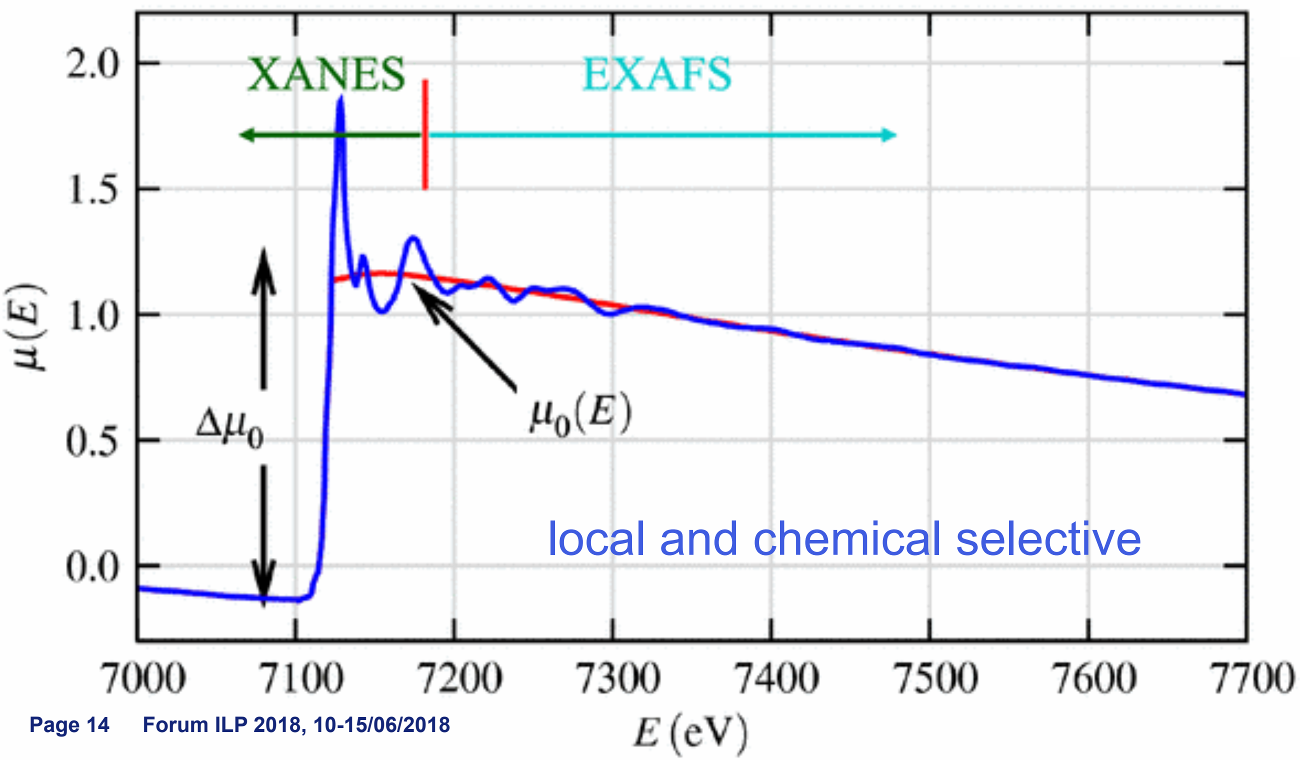
- small focal spot ~ few μm
- high flux (~ 10^{14} ph/s)

X-RAY ABSORPTION SPECTROSCOPY

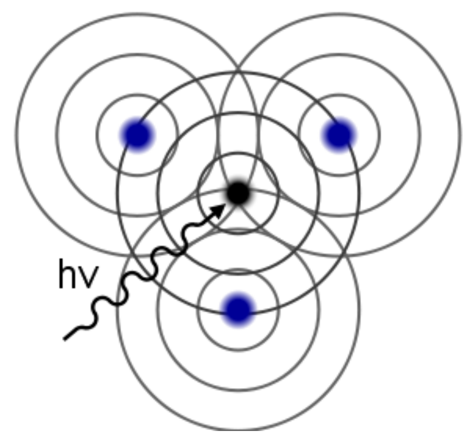


$$I_1 = I_0 e^{-\mu l}$$

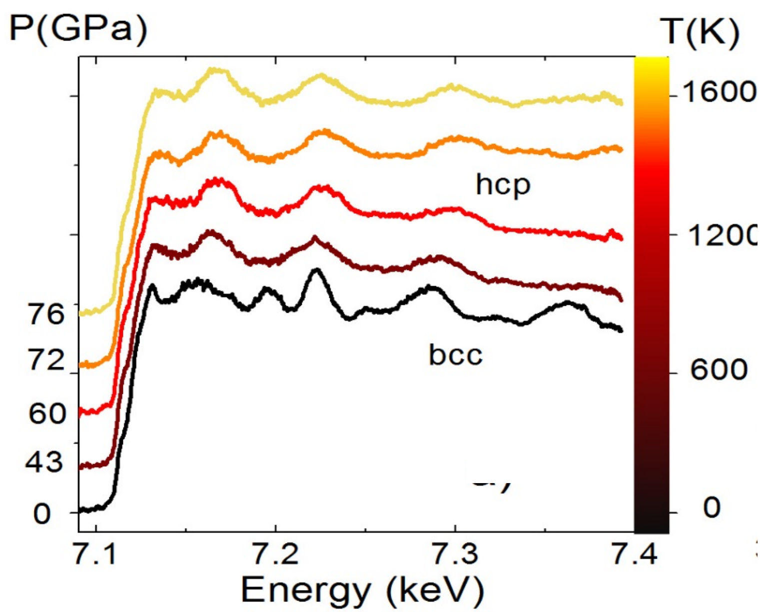


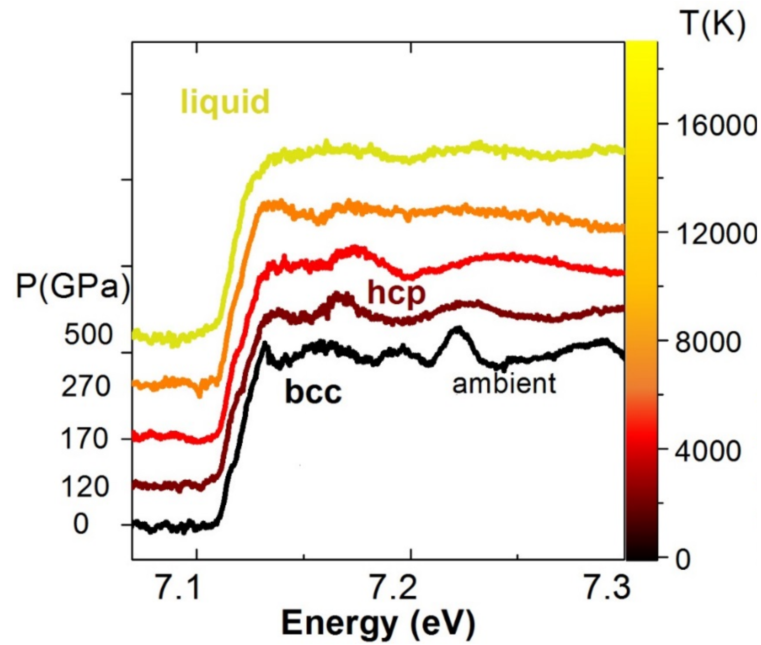


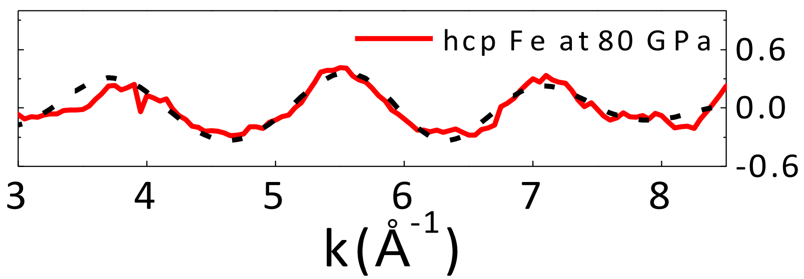
local and chemical selective

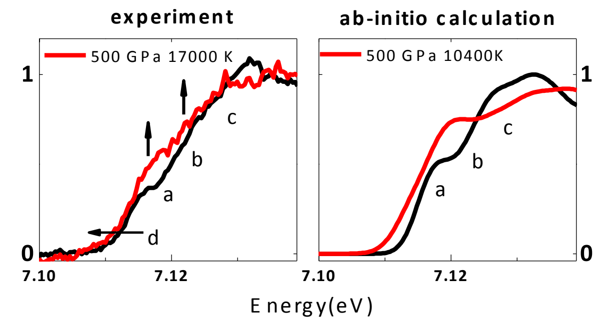


IRON: SOLID-SOLID AND SOLID-LIQUID TRANSITIONS







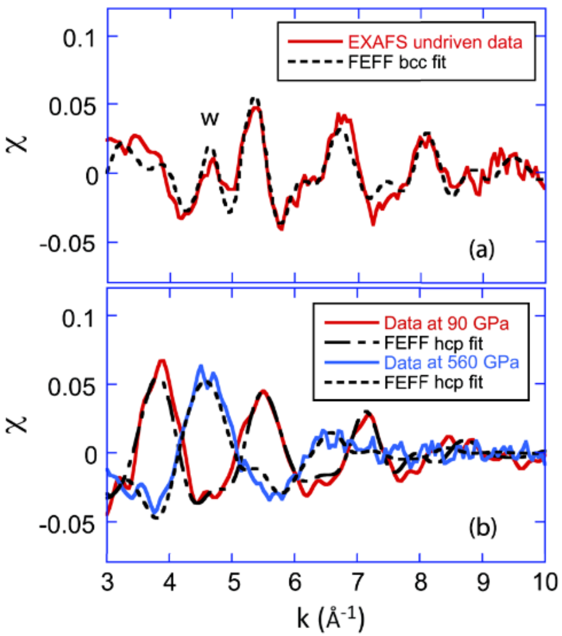


the data quality allows for the comparison to theoretical models

R. Torchio et al. Scientific Reports 2016

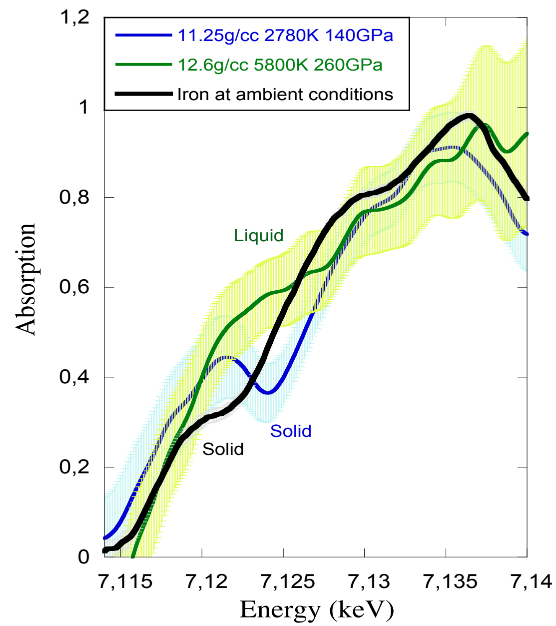
XAS STUDIES ON LASER SHOCKED FE

High Power Laser Facility
OMEGA
ramp compression



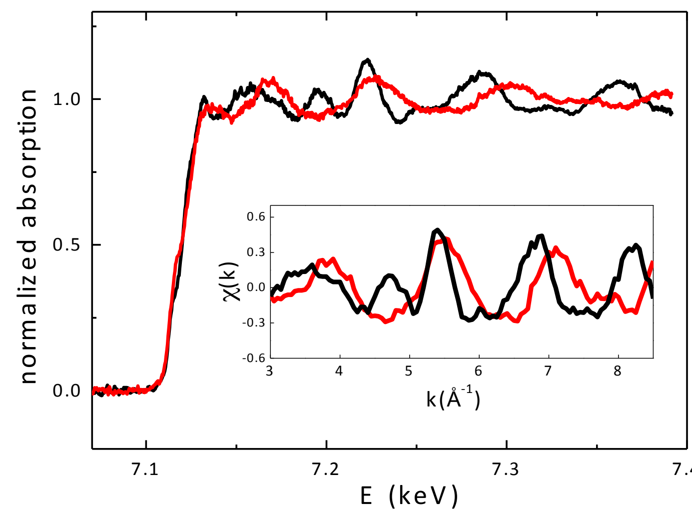
Ping et al., PRL 2013

X-ray Free Electron Laser
LCLS
shock



M. Harmand et al., PRB 2015

Synchrotron
ESRF
shock



R. Torchio et al. SR 2016

largest P, T range
single shot EXAFS

out of equilibrium states
photon flux

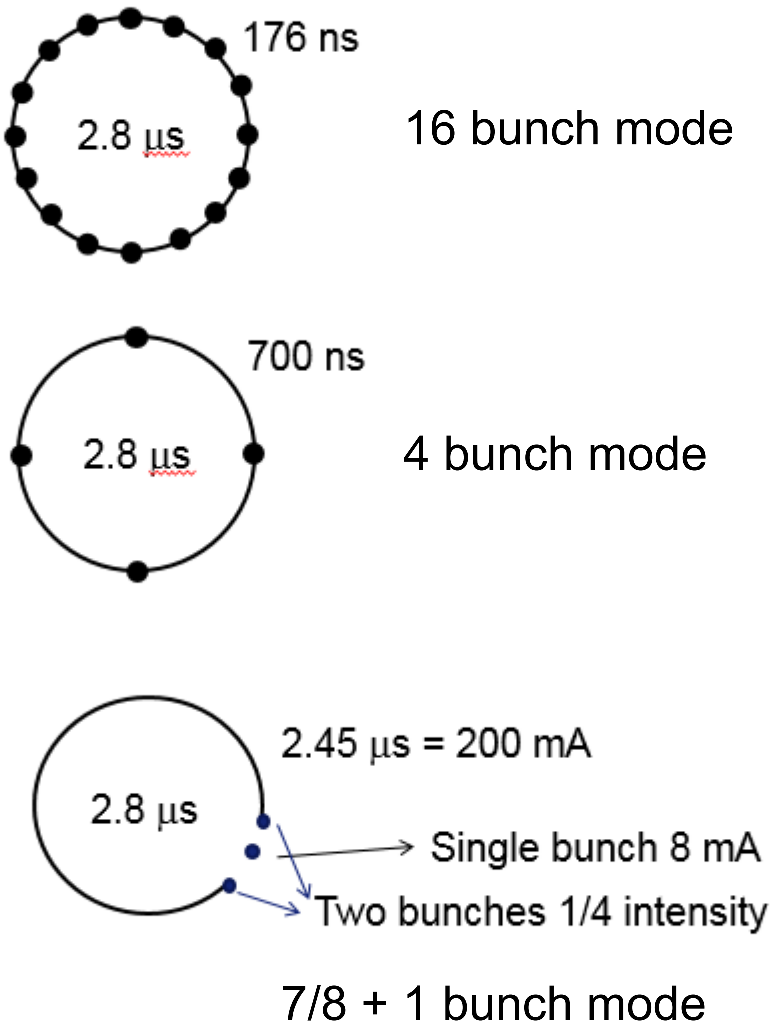
single shot XANES EXAFS
price (13K$/day)
availability and stability

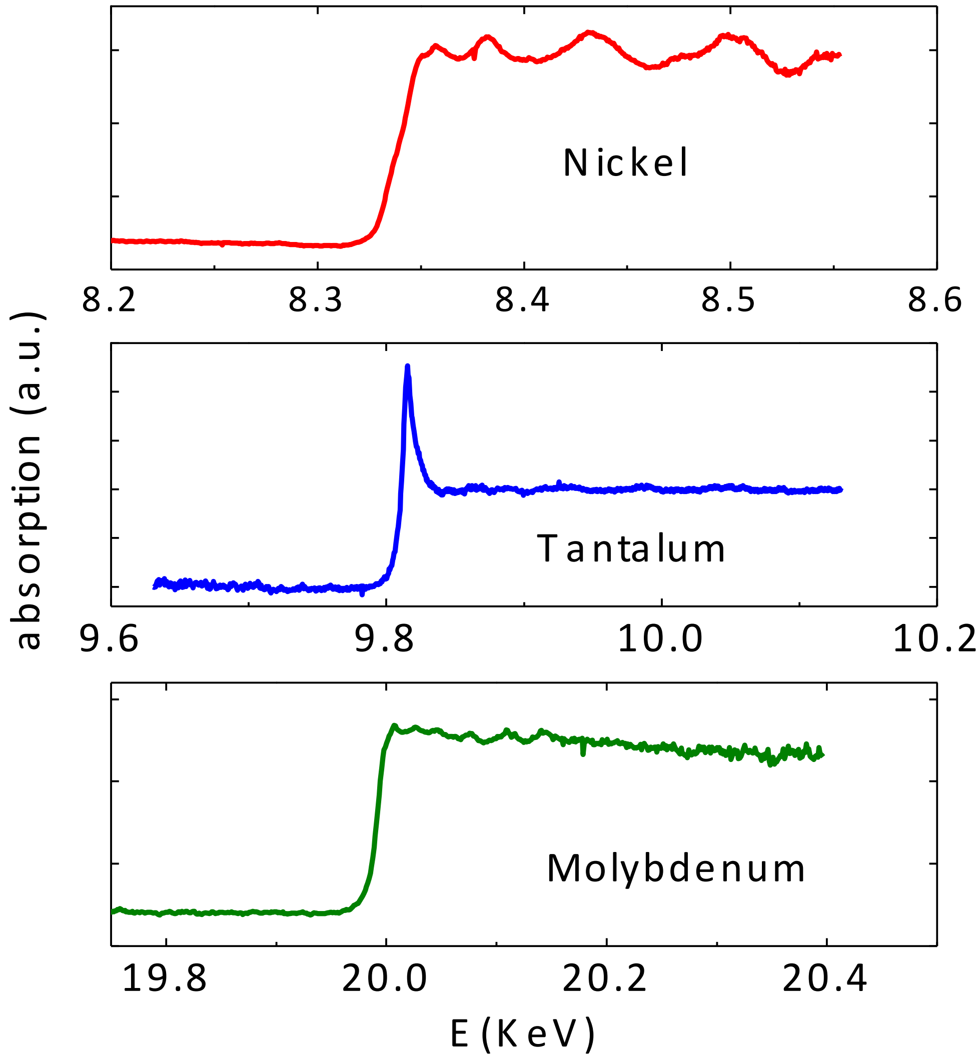
only EXAFS
cost and availability
(8 shots/day, 15K$/shot)

energy range
beam instability
cost (204K$/day)

limited P,T range
diagnostics

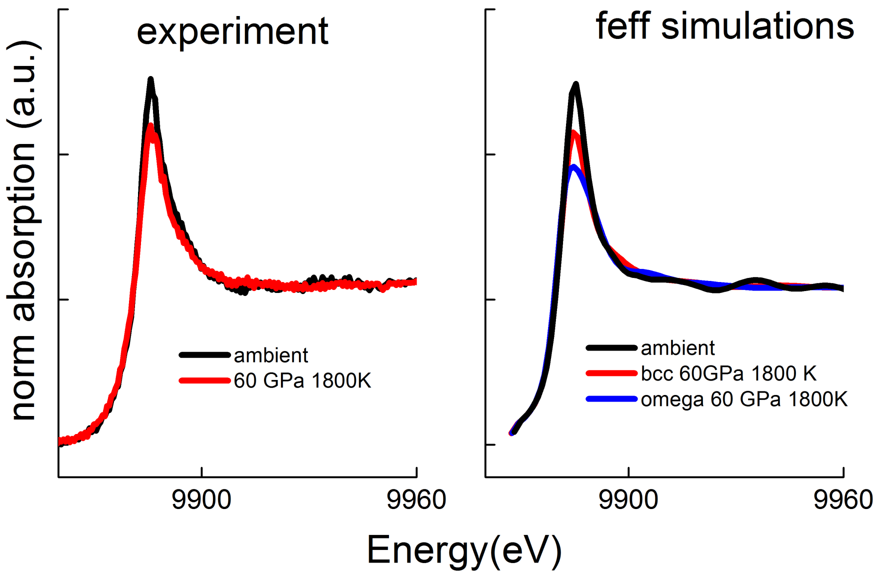
DIFFERENT TIMING MODES AND DIFFERENT ENERGIES





Single bunch XAS at Ni, Ta and Mo

O. Mathon et al., HPR 36, 404 (2016)

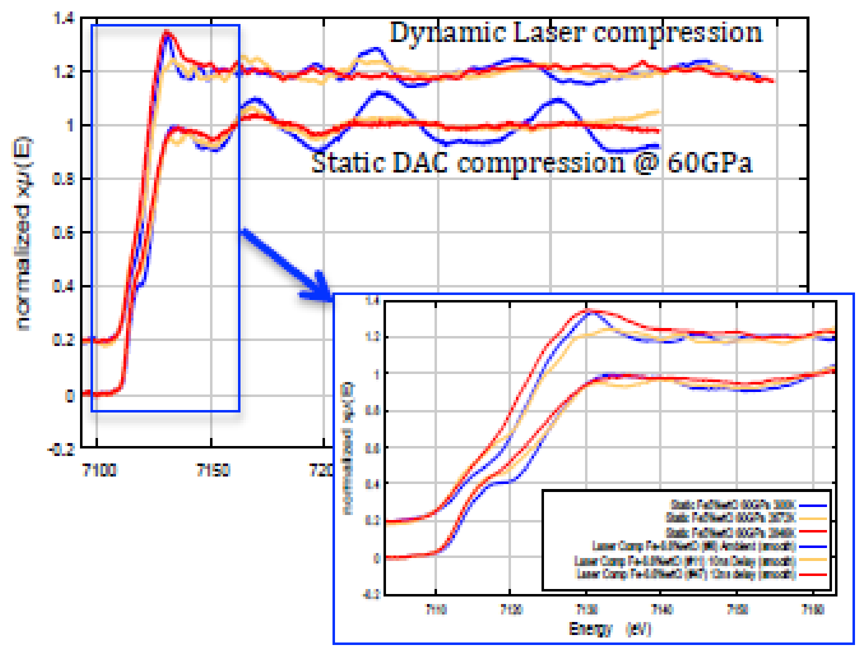


Local Structure of laser shocked Ta

A. Sollier et al., to be published

Local structure of laser shocked Fe-6.6%wtO

M. Harmand et al., to be published



HPLF I
Technical design

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 654220

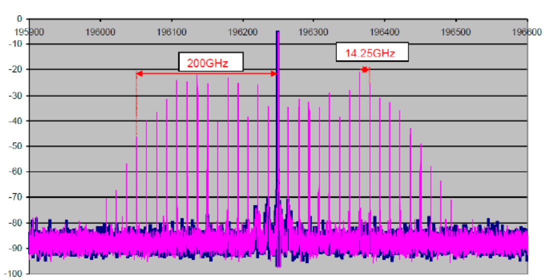
LASER provided by *Amplitude Laser Group (Lisses, Fr. and San Jose, USA)*

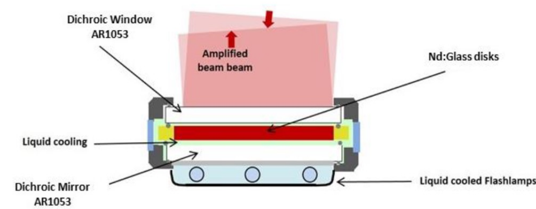
FRONT-END
15J @ 1053 nm
2-15 ns
Pulse shaped

Power Amplifier
Disk Amplifier
Head (DAH)

- 3 DAH: 108J @ 1053 nm, 4-15 ns
- 5 DAH: 200J @ 1053 nm, 6-15 ns
- Green option

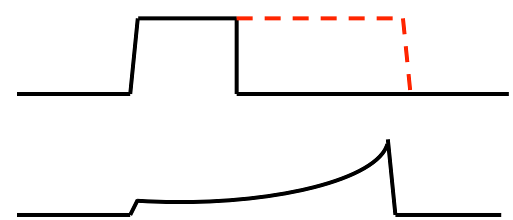
Front-end
- Pulse generation (CW laser)
- Pulse shaping
- Spectral broadening
- Pre-amplification stages





Amplification chain
- Nd:Glass DAH
- Liquid cooled amplifiers
- Pumped by flash lamps
- 3 DAHs for HPLF1
- Compatible 5 DAHs (upgrade)

Output
- 1-100 J adjustable
- Top-hat spatial profile N>8
- Adjustable temporal profile
  flat top variable (2-15ns)
  ramps t^2, t^3, t^4
- 1 shot every 4 minutes
- Jitter < 26 ps RMS



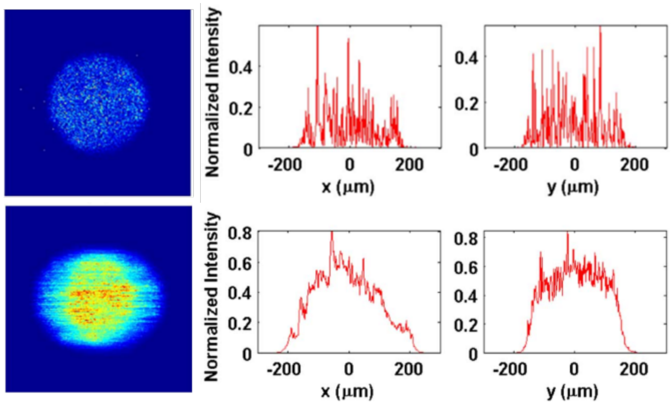
LASER CHARACTERISTICS : FRONT-END

LASER provided by *Amplitude Laser Group (Lisses, Fr. and San Jose, USA)*

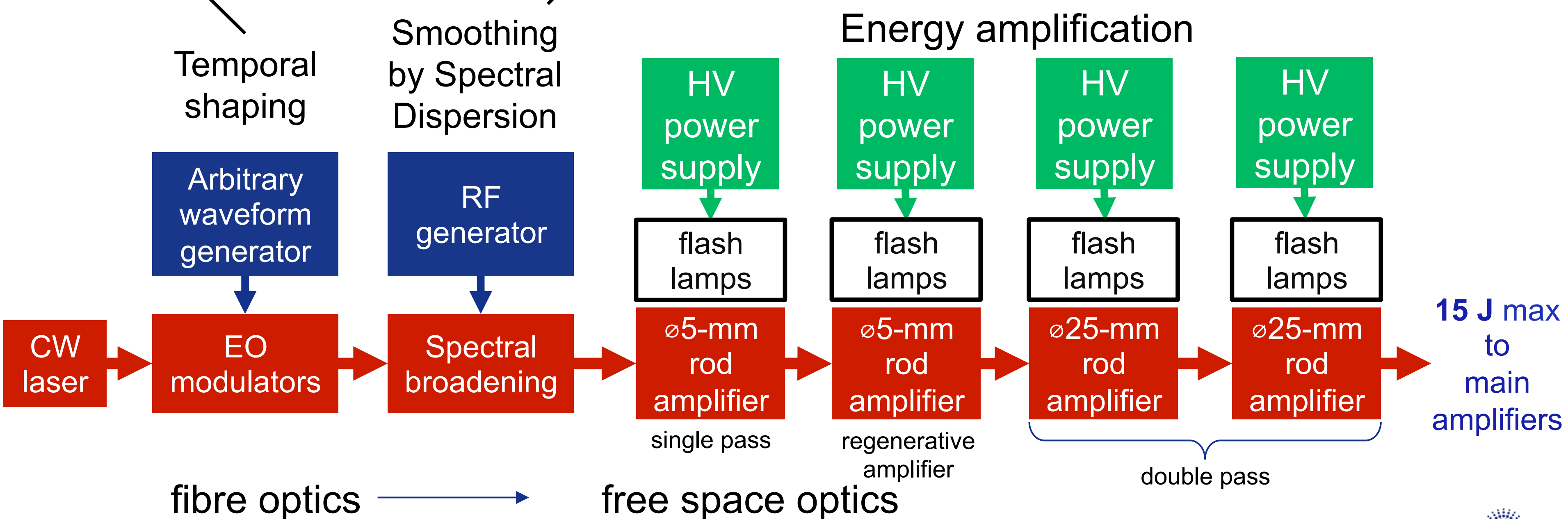
Shape control: 0.25 ns step
Jitter < 26 ps
Rising edge: 0.25ns 20-80%
Modulation < 3% RMS
Shot-to-shot stability < 2% rms
Contrast > 10^5

No SSD

SSD



From Jiang et al., J. Opt. Soc. Am. A (2013)



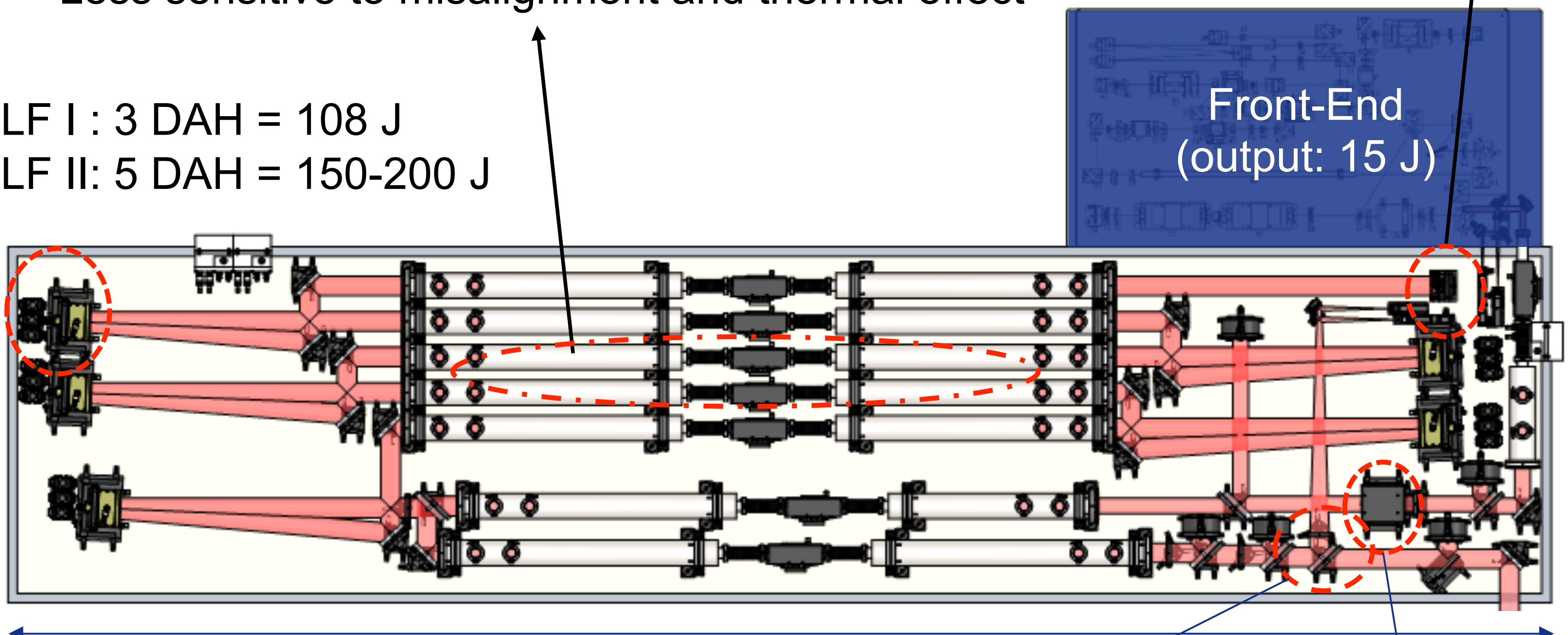
LASER CHARACTERISTICS AMPLIFICATION

LASER provided by *Amplitude Laser Group (Lisses, Fr. and San Jose, USA)*

Relay imaging propagation
- Optimum beam quality on critical components
- Safer for optical elements
- Less sensitive to misalignment and thermal effect

HPLF II
- Deformable mirror

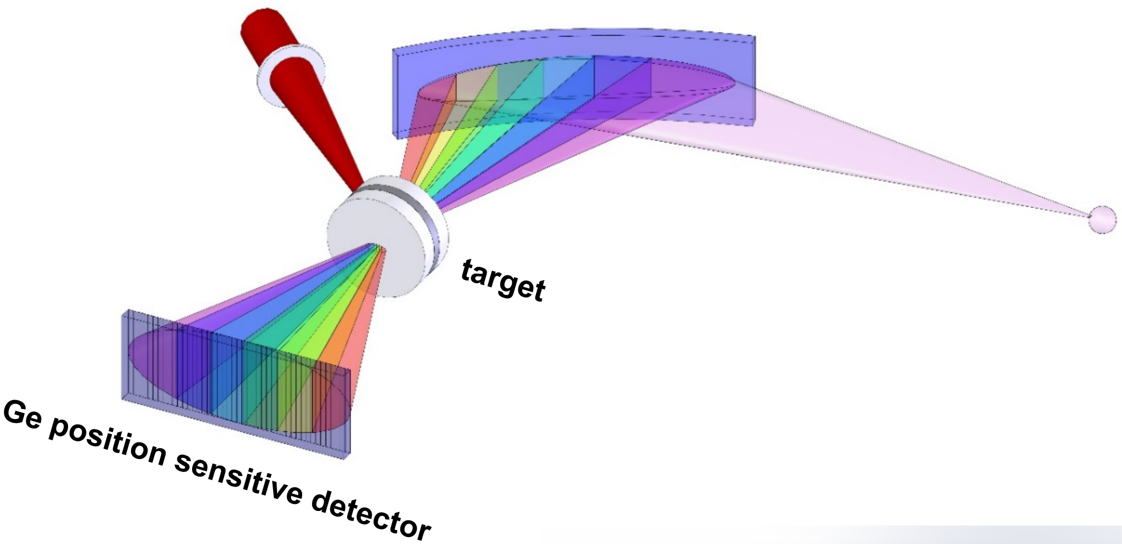
DAH
- HPLF I : 3 DAH = 108 J
- HPLF II: 5 DAH = 150-200 J

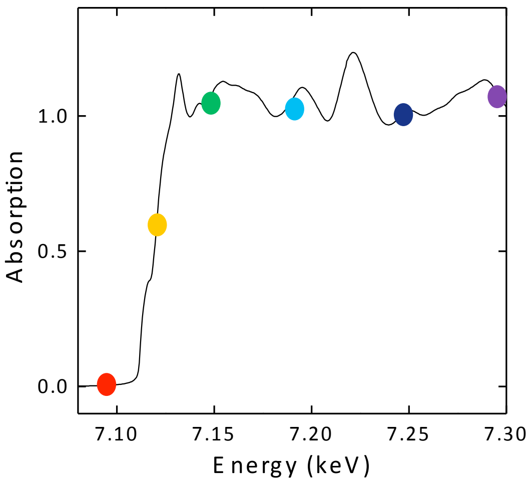


Backstop pockels

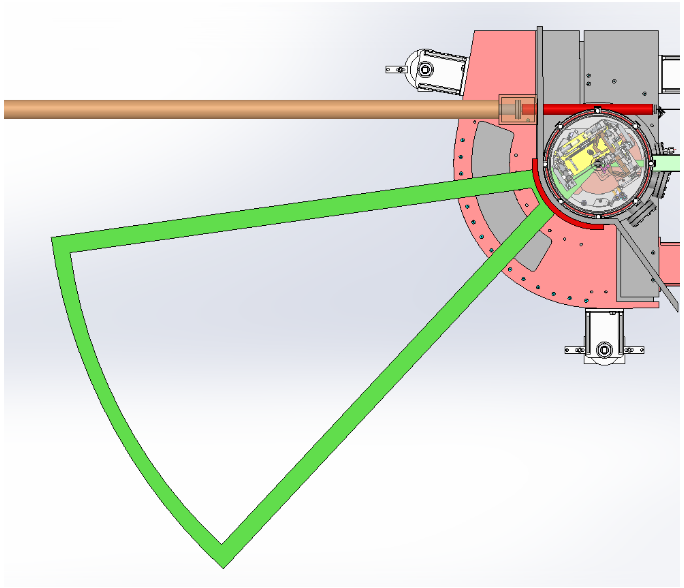
Shot-to-shot characterization
- Spatial and temporal profile

ID24 beamline dispersive setup



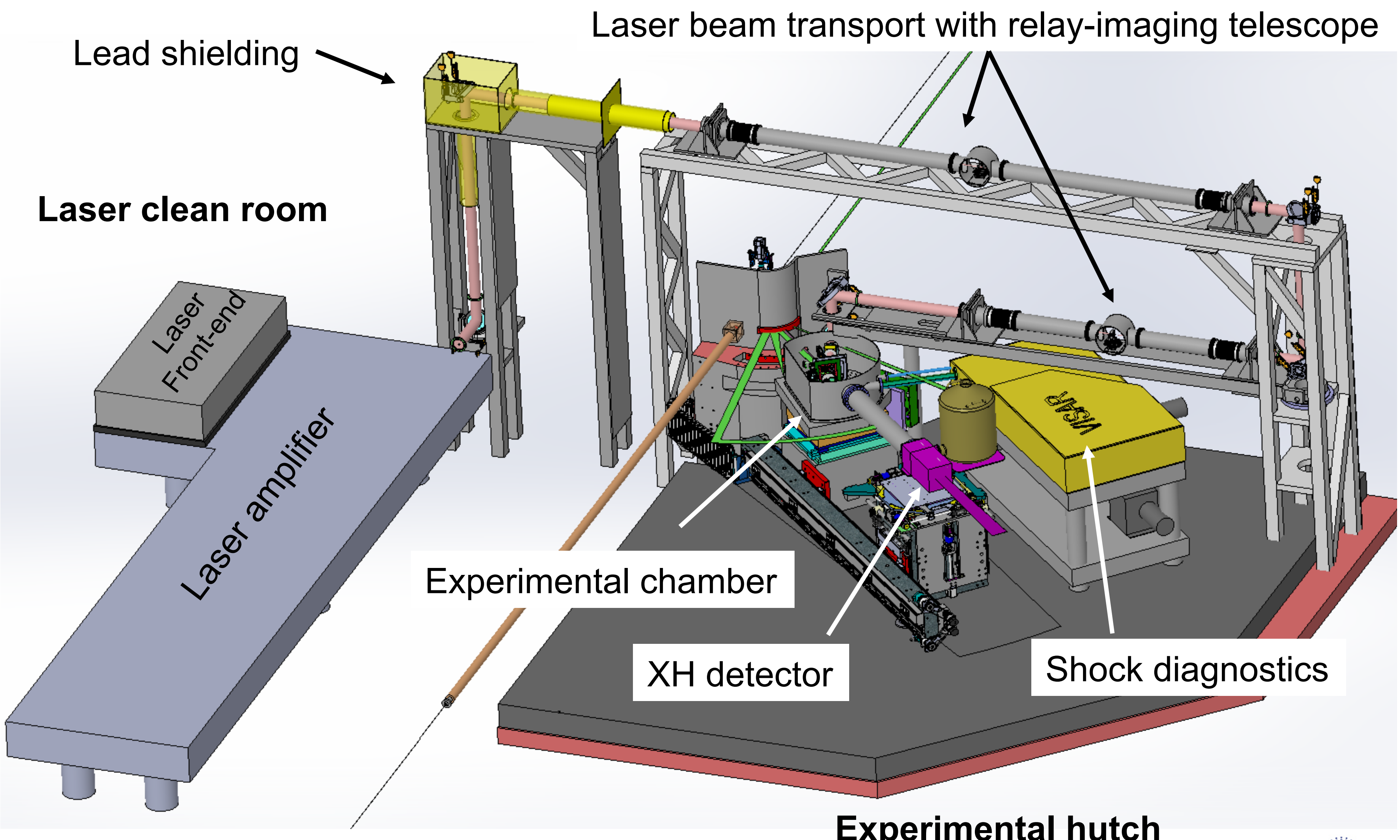


energy range: 5-28 keV
2θ bench: 47°-8°

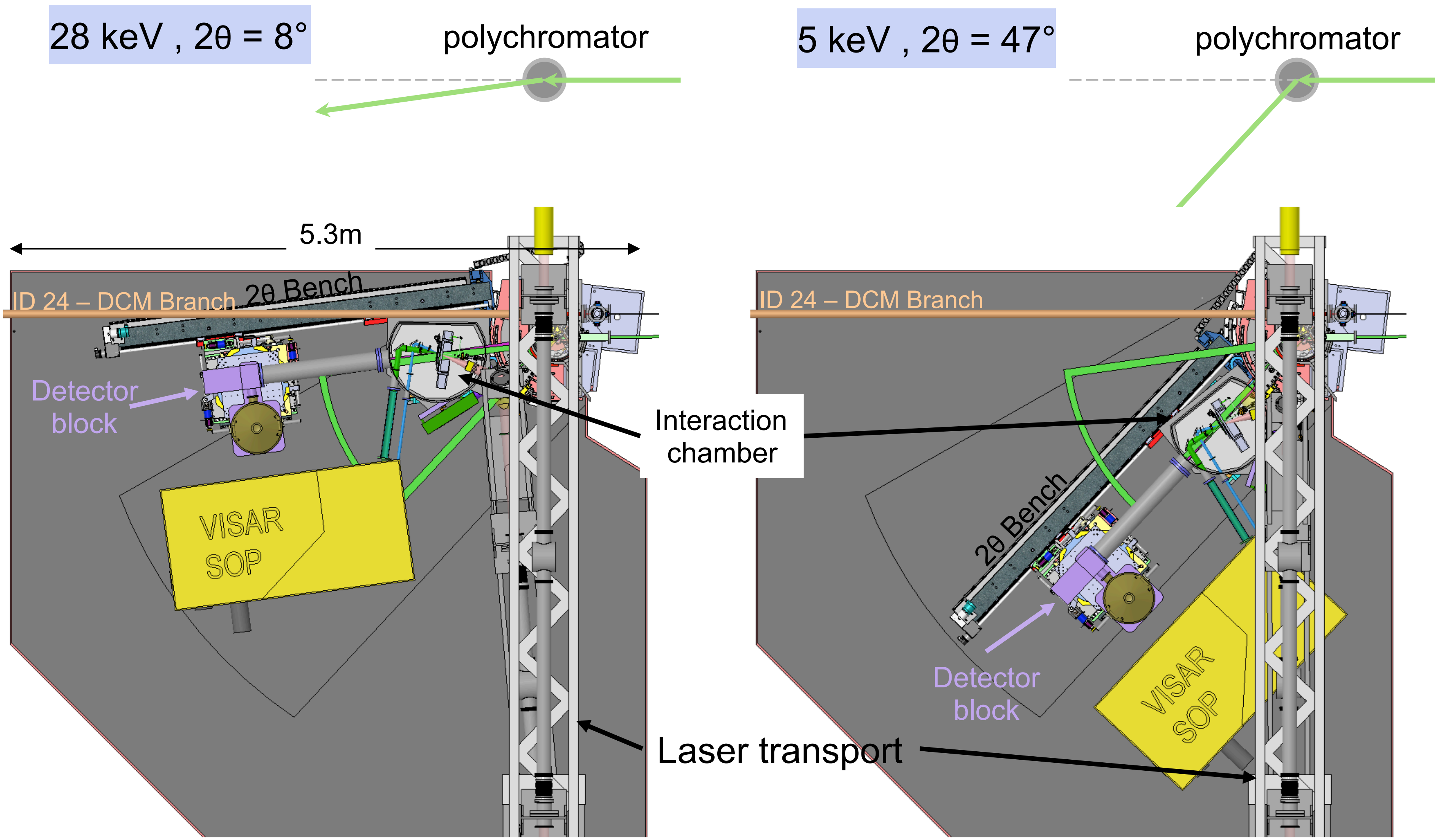


at each different E
the sample environment
has to rotate
around the crystal

LASER ENVIRONMENT AND TRANSPORT

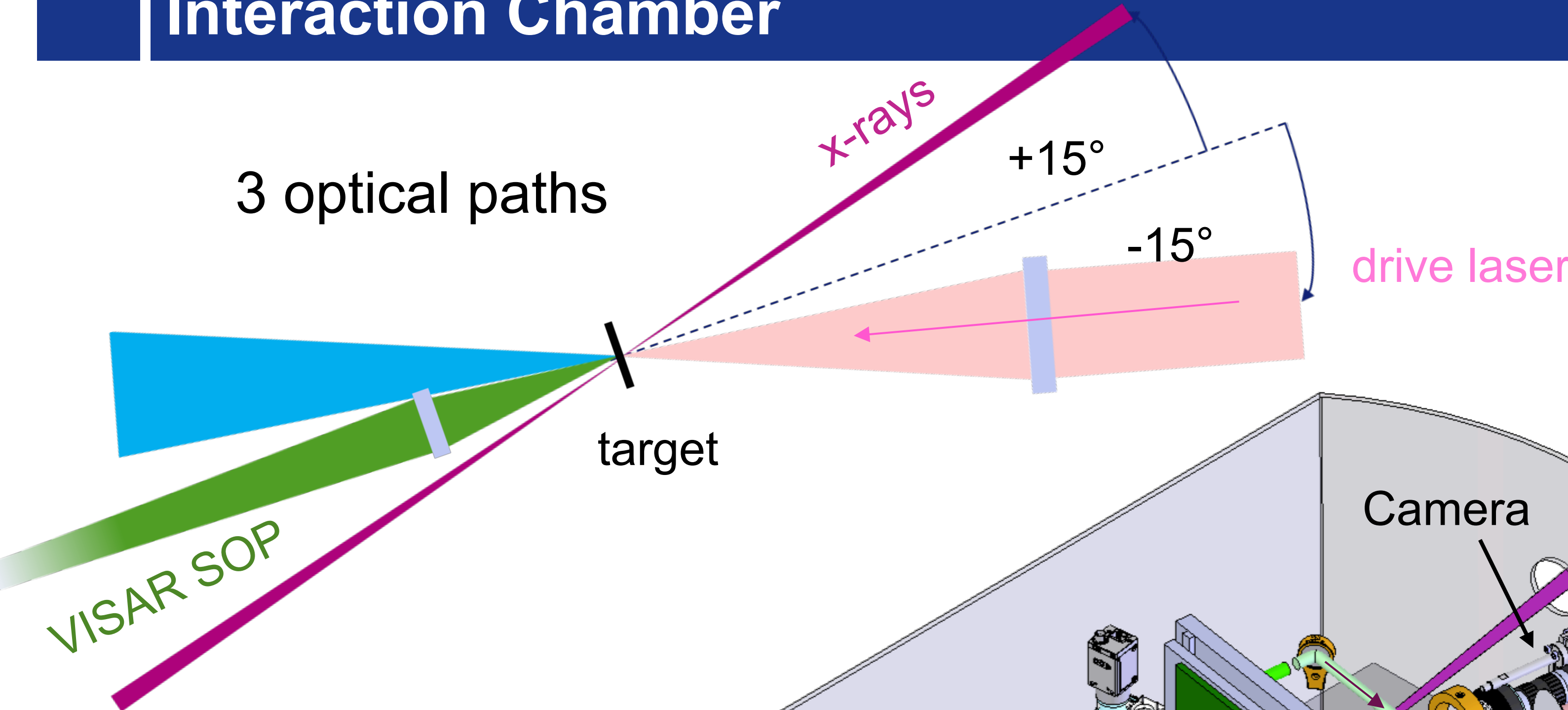


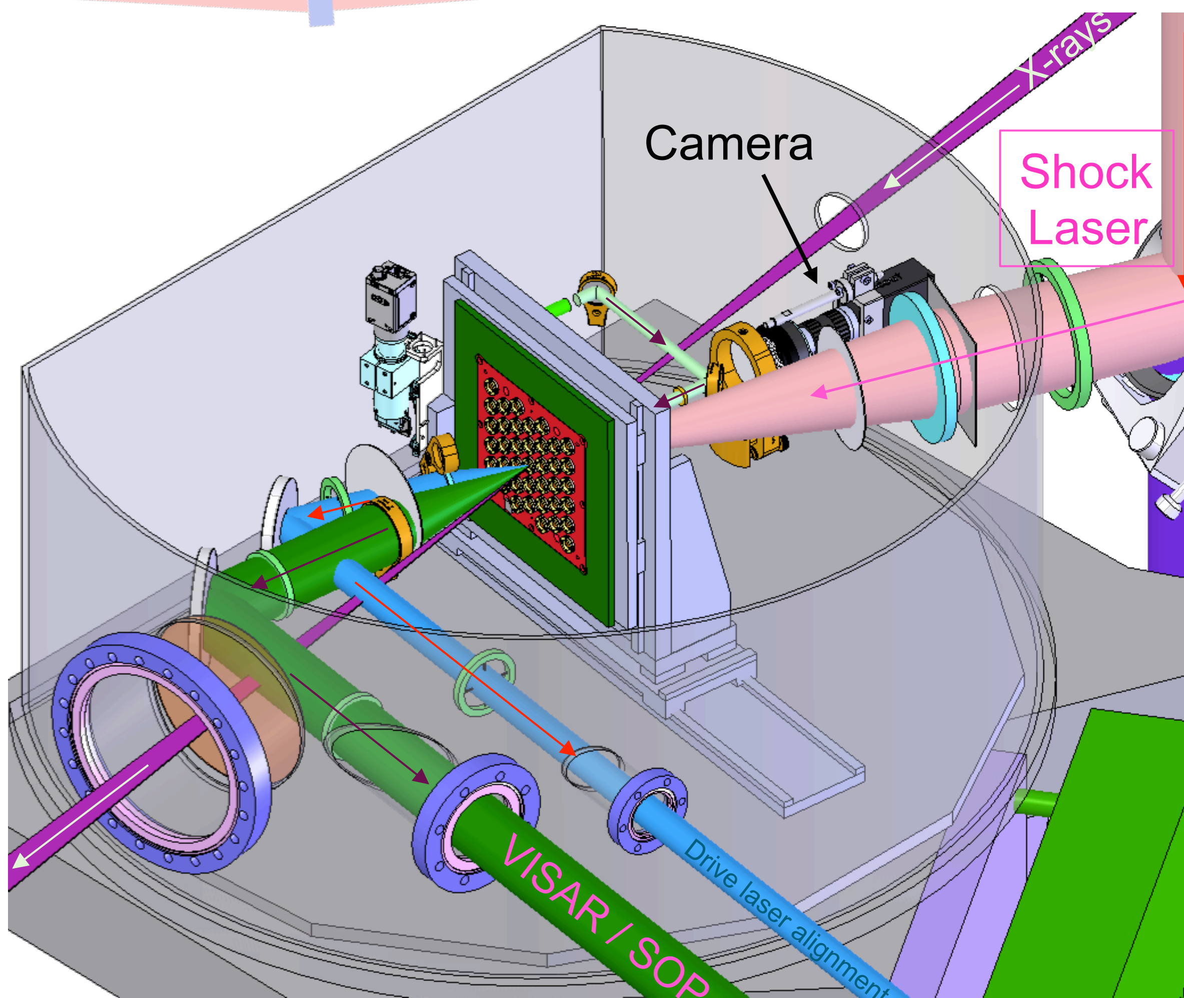
EXPERIMENTAL HUTCH



Interaction Chamber

3 optical paths





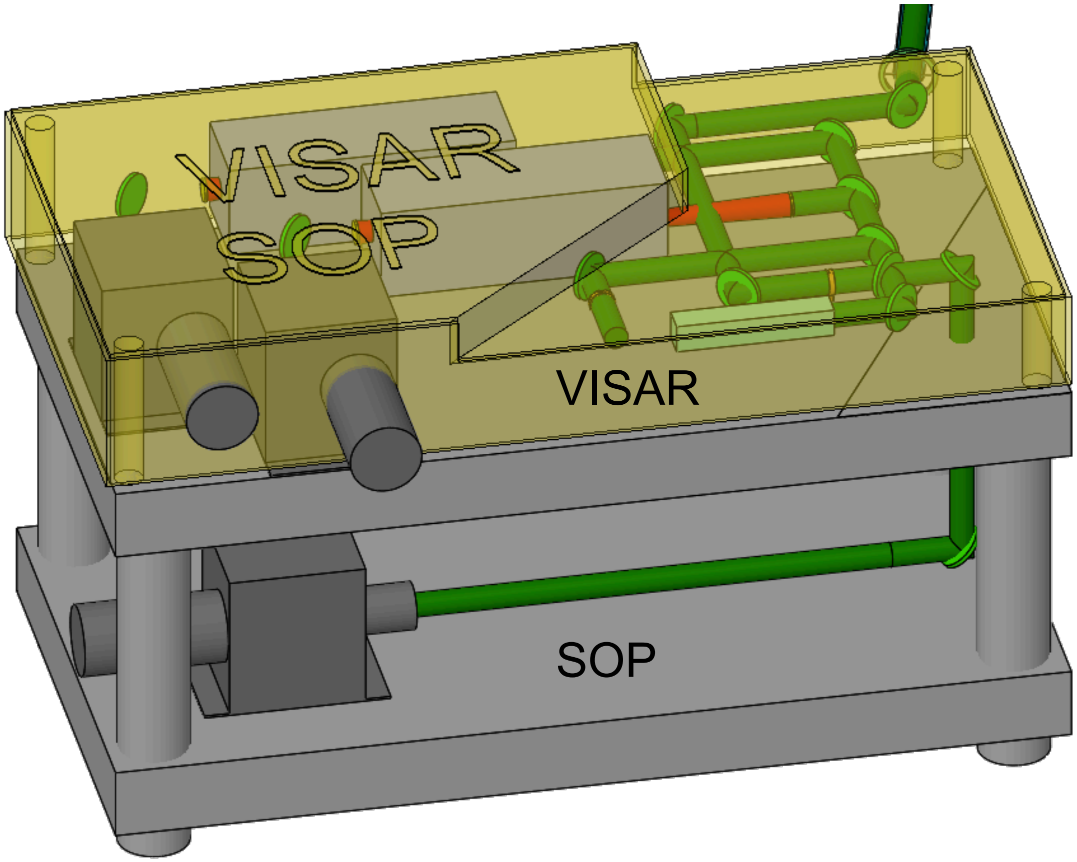
X-rays: local structure (XAS)
VISAR/SOP: measure P, T
Drive laser: extreme P, T
Alignment: drive laser

target holder EUCALL

Velocity Interferometer System for any Reflector (VISAR)
Streaked Optical Pyrometry (SOP)

P, T, ρ

measure the spatial and temporal evolution of hydrodynamic parameters
→ full compression history of the sample and planarity of the shock propagation



HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

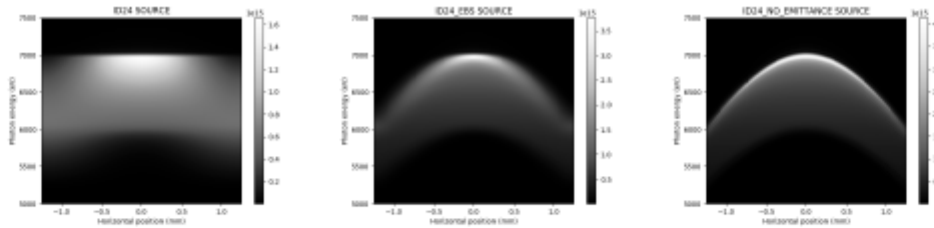
ESRF-EBS

the future:
EBS and HPLF II

HPLF-I AND HPLF-II TOWARD EBS

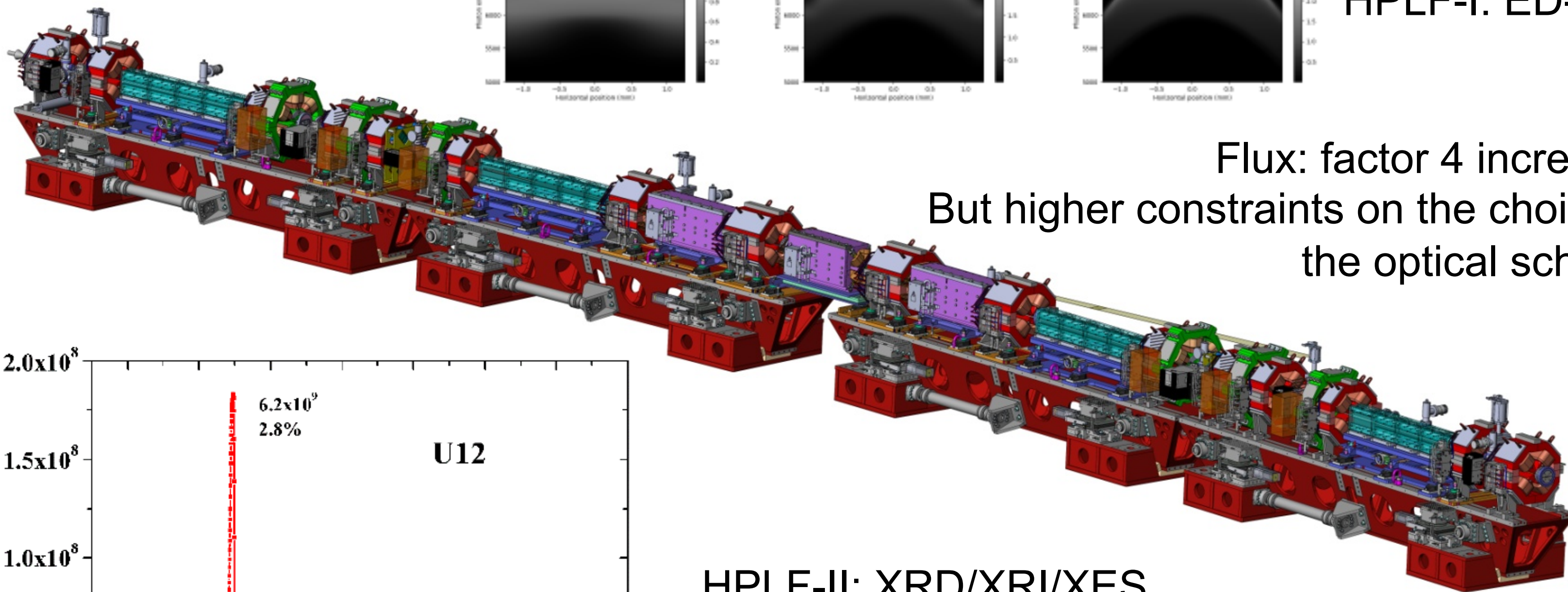
ESRF Extremely Brilliant Source (EBS)

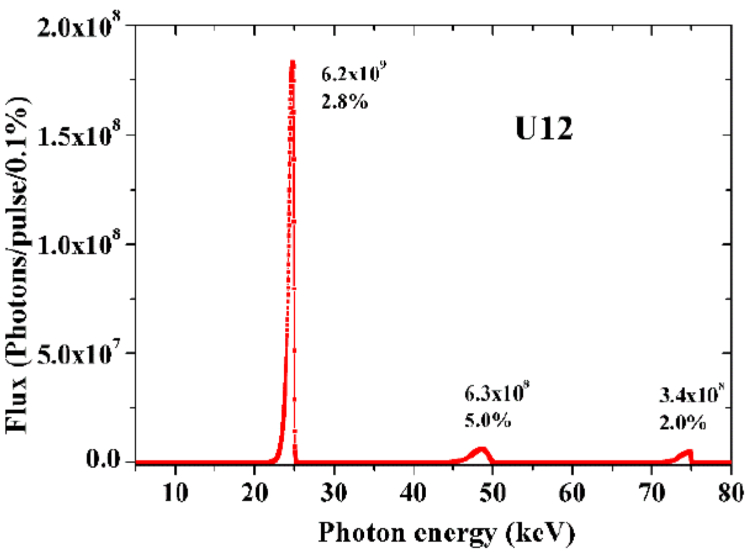
Horizontal emittance: **ε_x = 4 nm → ε_x = 0.15 nm**



HPLF-I: ED-XAS

Flux: factor 4 increases
But higher constraints on the choice of the optical scheme



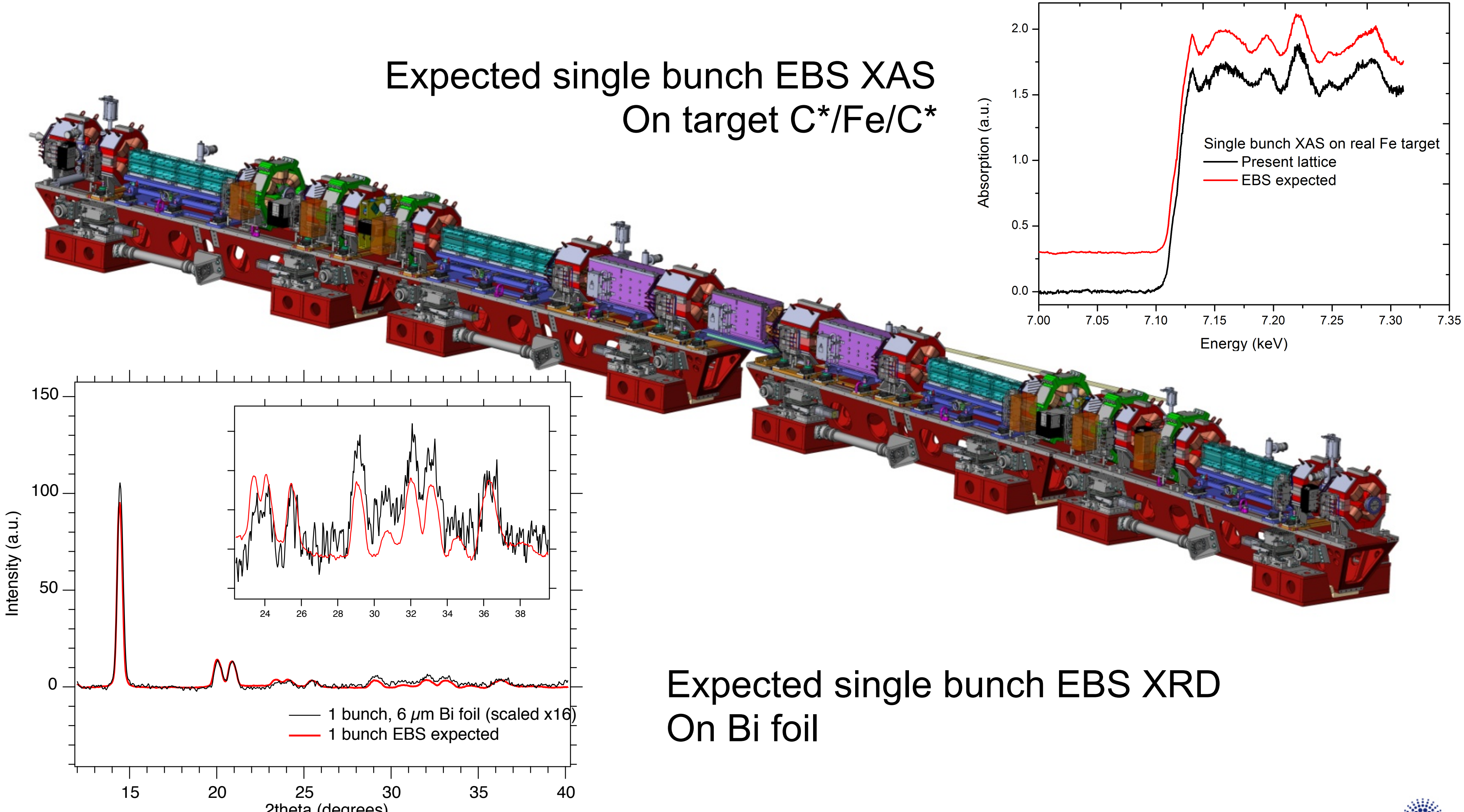


HPLF-II: XRD/XRI/XES
Flux: factor 5 increase
Toward higher data quality in XRD + lower Z
Toward higher sensitivity/spatial resolution and denser materials in XRI

ESRF Extremely Brilliant Source (EBS)

Horizontal emittance: ε_x = 4 nm → ε_x = 0.15 nm

Expected single bunch EBS XAS
On target C*/Fe/C*



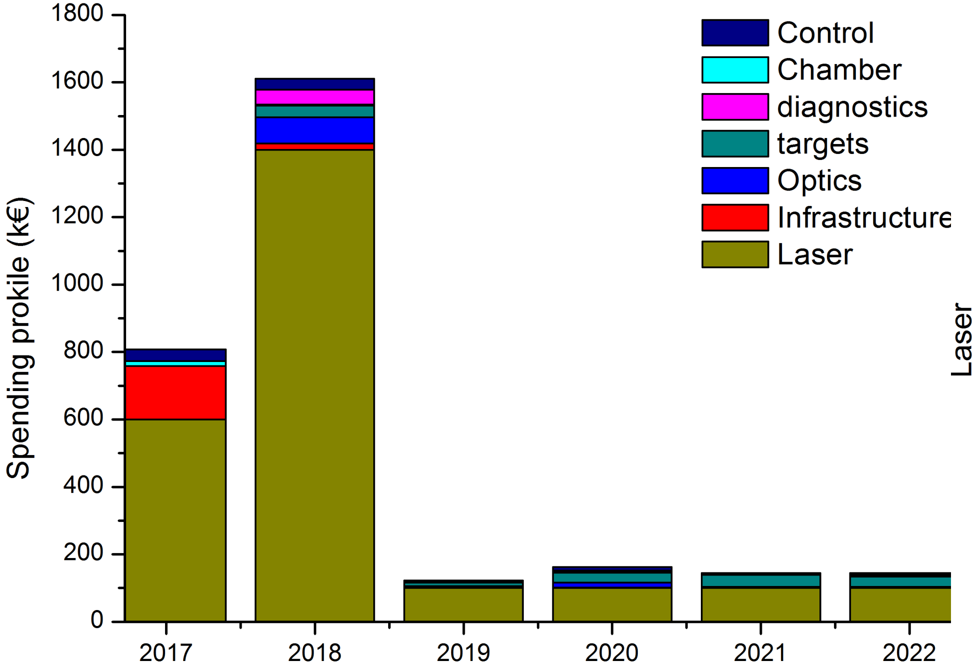
Expected single bunch EBS XRD
On Bi foil

Dynamic compression drivers at modern X-ray light sources

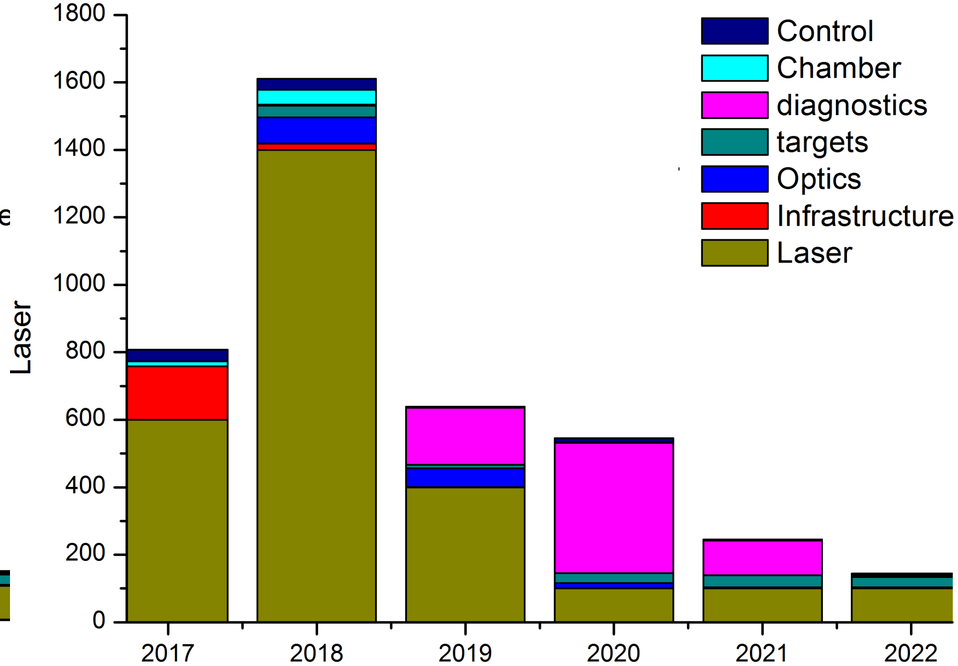
1 working – 4 becoming operational

ESRF facility the only one to offer multiple techniques

SPENDING PROFILE



HPLF-I project - Spending profile up to 2022
ESRF funding.



HPLF-I project - Spending profile up to 2022
External + ESRF funding

+ 1 ID24 dedicated scientist
 1 laser engineer

shock diagnostics
second harmonic (LBO crystal)
deformable mirror
targets

SUMMARY / CONCLUSION

High Power Laser Facility (HPLF) is an ESRF initiative to develop instrumentation to study matter under dynamic compression.

It includes:

HPLF-0 (2014-2018)

Evaluation tests in XRD/XRI/XAS and conceptual design

HPLF-I (2018-2021)

Installation of a 100 J pulsed shaped laser on ED-XAS ID24 beamline

2018: laser front-end (15J, 10ns)

2021: laser amplifier (100J, 4 ns)

HPLF-II (from 2023)

Extension of the facility to offer additional X-ray diagnostics: XRD, XRI, XES

Upgrade of the laser power to 200 J

EBS will improve the flux for single bunch XAS/XRD/XRI

Thank you for your attention

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