European XFEL
Enlightening Science

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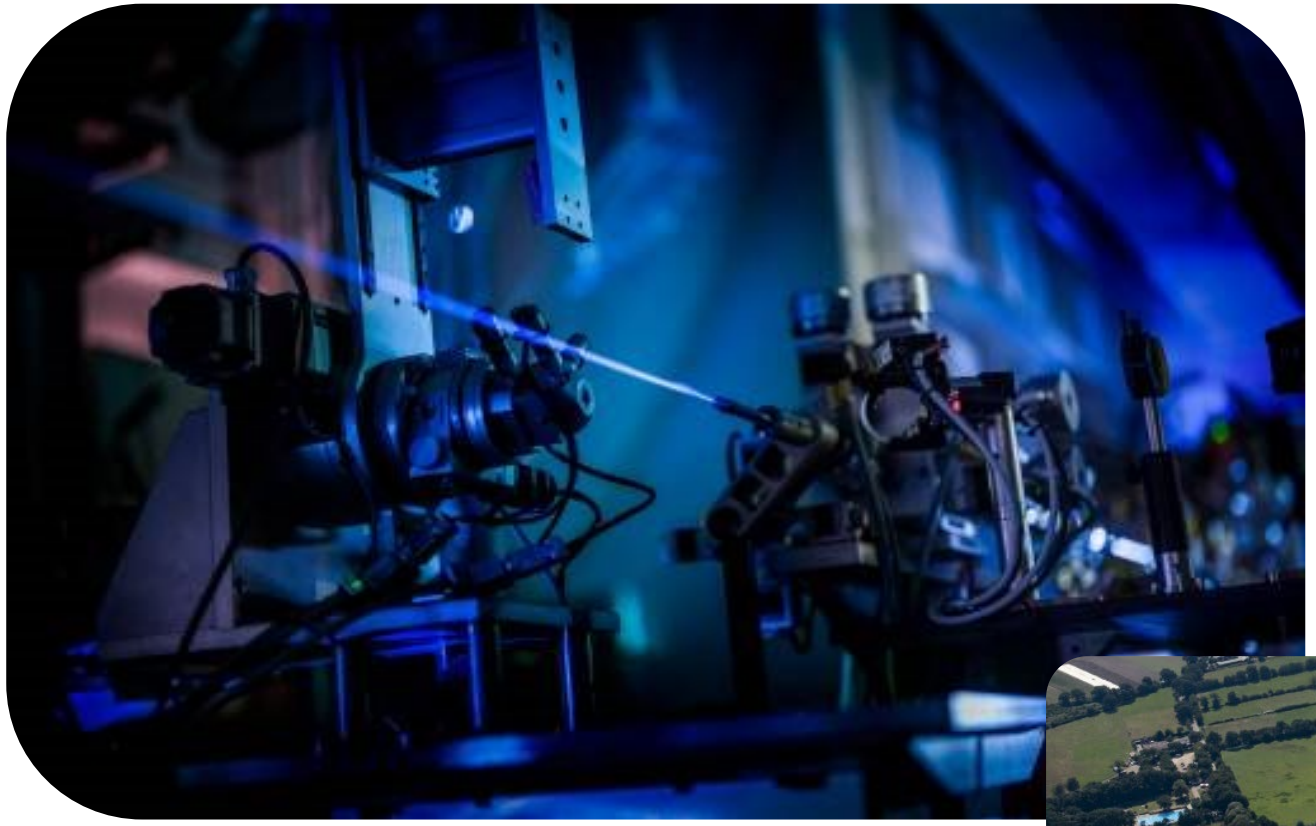
European XFEL—a leading new research facility

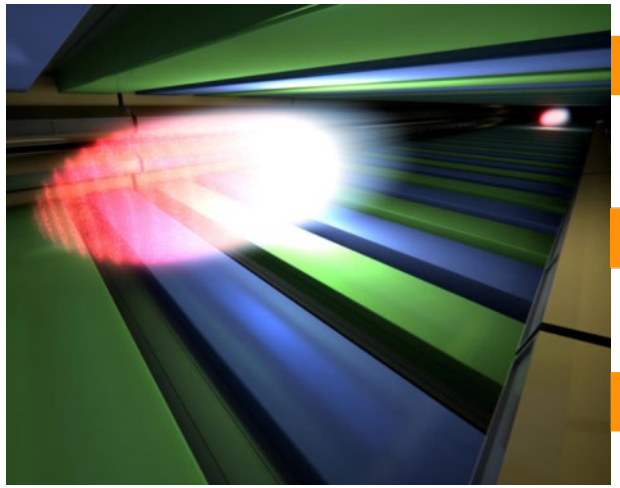


The European XFEL is a new research facility that uses high-intensity X-ray light to study the structure of matter.

- User facility with more than 500 employees (+250 from DESY)
- Location: Hamburg and Schenefeld, Germany

Schenefeld research campus on 14 August 2017

What can the European XFEL do?



X-ray light
See samples at atomic resolution

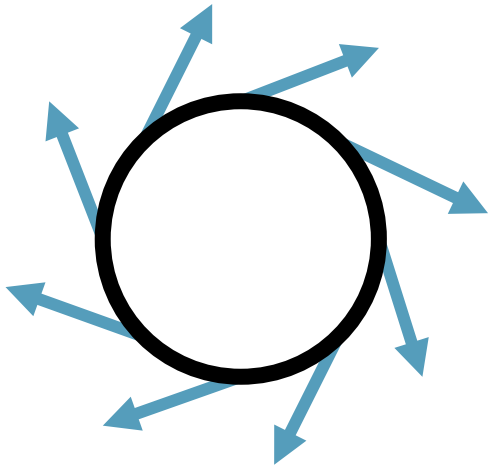
Ultrashort flashes
Film (bio-)chemical reactions

Intense X-ray pulses
Study single molecules or tiny crystals

Using X-rays to explore matter

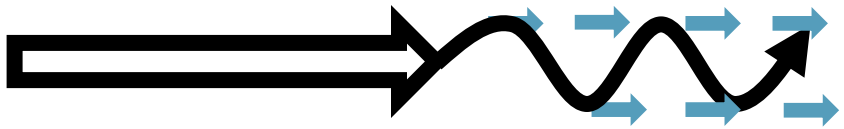
Synchrotrons

- Electrons traveling in a wide circular path, emitting light as they change directions
- Light is UV or X-ray, but not coherent



Free-Electron Lasers

- Electrons accelerated in a straight line and manipulated to generate light
- Light is coherent and intensely bright in very short pulses, showing objects in even more detail and revealing processes



About European XFEL

- Organized as a non-profit corporation in 2009 with the mission of design, construction, operation, and development of the free-electron laser
- Supported by 12 partner countries
- Total budget for construction (including commissioning)
  - 1.25 billion € at 2005 prices, about 140 M€ operating budget
  - 600 M€ contributed in cash, over 550 M€ as in-kind contributions (mainly manufacture of parts for the facility)

European XFEL

2017 - 2020

Three years of operation including the pandemic situation

1261

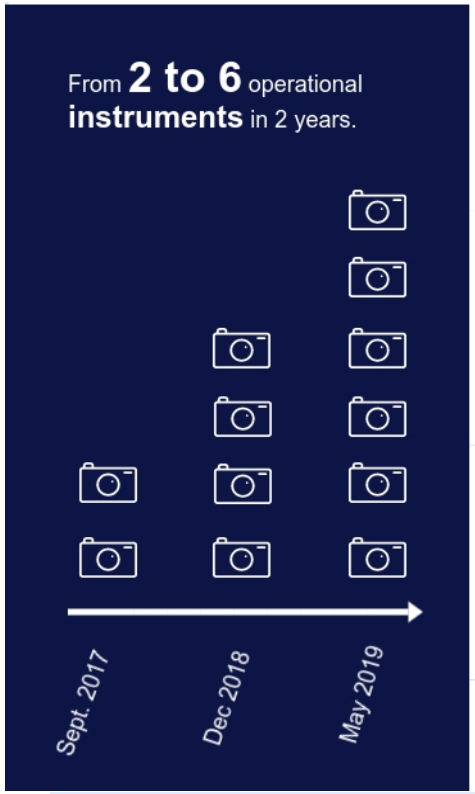
users from across the world have visited European XFEL for their experiments since operation began in September 2017.

95

experiments have been carried out at the facility.

109 Proposals finished or scheduled (i.e. accepted)

466 Proposals finished or scheduled (i.e. accepted)



6036

Hours of beamtime provided for user experiments since operation began.

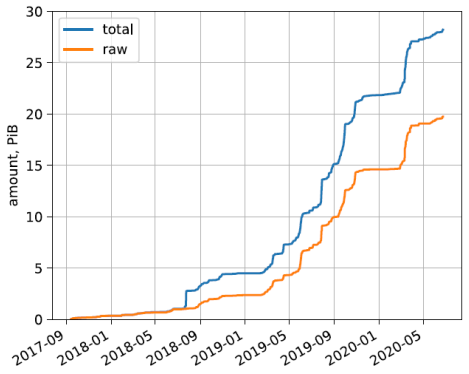
19

Petabytes of data produced during user experiments.

21

User publications published in peer-reviewed journals during the first three years. Many more are in preparation.

Data profile



instrument	dtype	proc	raw	bytes total
SPB		3.2 PiB	8.5 PiB	11.6 PiB
MID		2.7 PiB	4.6 PiB	7.2 PiB
SCS		352.9 TiB	2.7 PiB	3.1 PiB
FXE		1.2 PiB	1.3 PiB	2.5 PiB
SQS		59.0 TiB	429.4 TiB	488.4 TiB
HED		18.4 TiB	25.6 TiB	44.0 TiB
total		7.5 PiB	17.5 PiB	25.1 PiB

European XFEL

2017 - 2022

Three years of operation including the pandemic situation

2448

users from across the world have visited European XFEL for their experiments since operation began in September 2017.

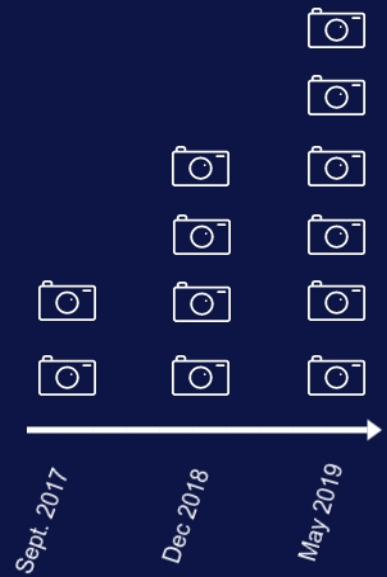
247

experiments have been carried out at the facility.

247 Proposals finished

901 Submitted experimental proposals

From **2 to 6** operational **instruments** in 2 years.



19 944

Hours of beamtime

provided for user experiments since operation began.

19 (2020), **80** (2023)

Petabytes of data

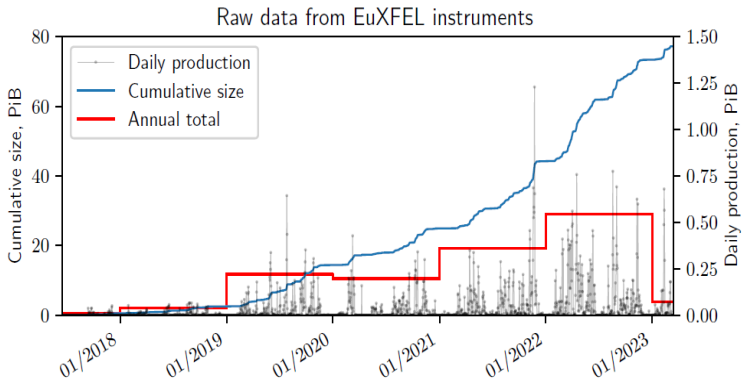
produced during user experiments.

55

User publications

published in peer-reviewed journals during the first three years. Many more are in preparation.

Data profile



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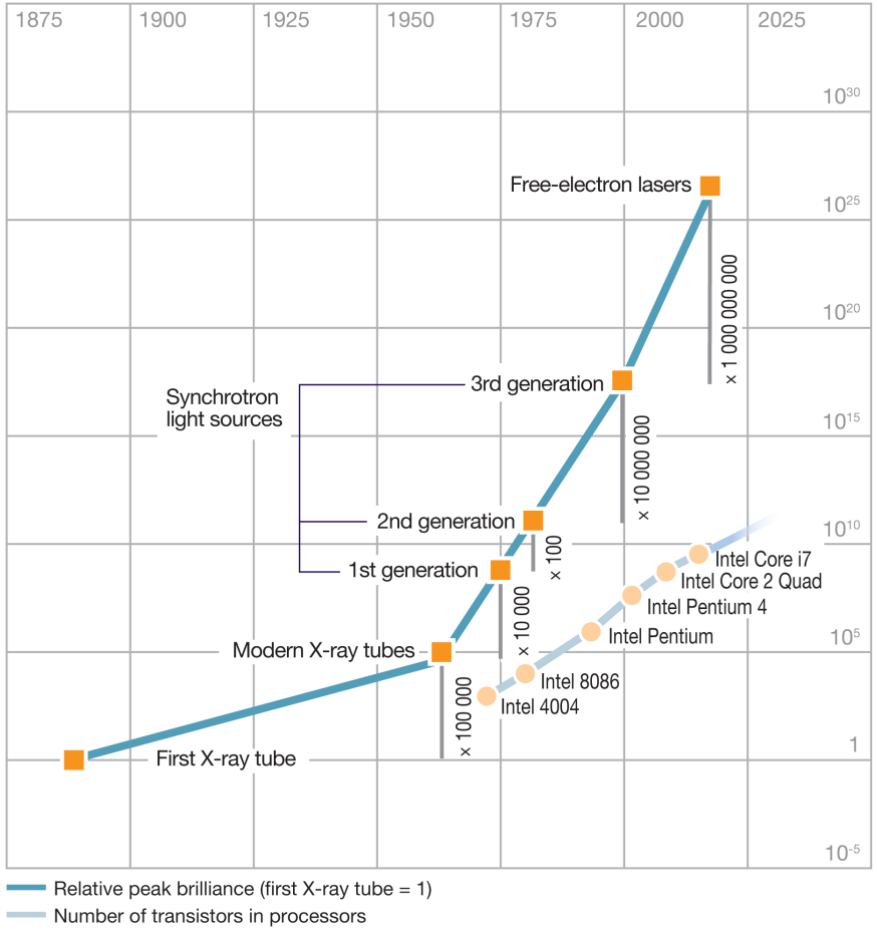
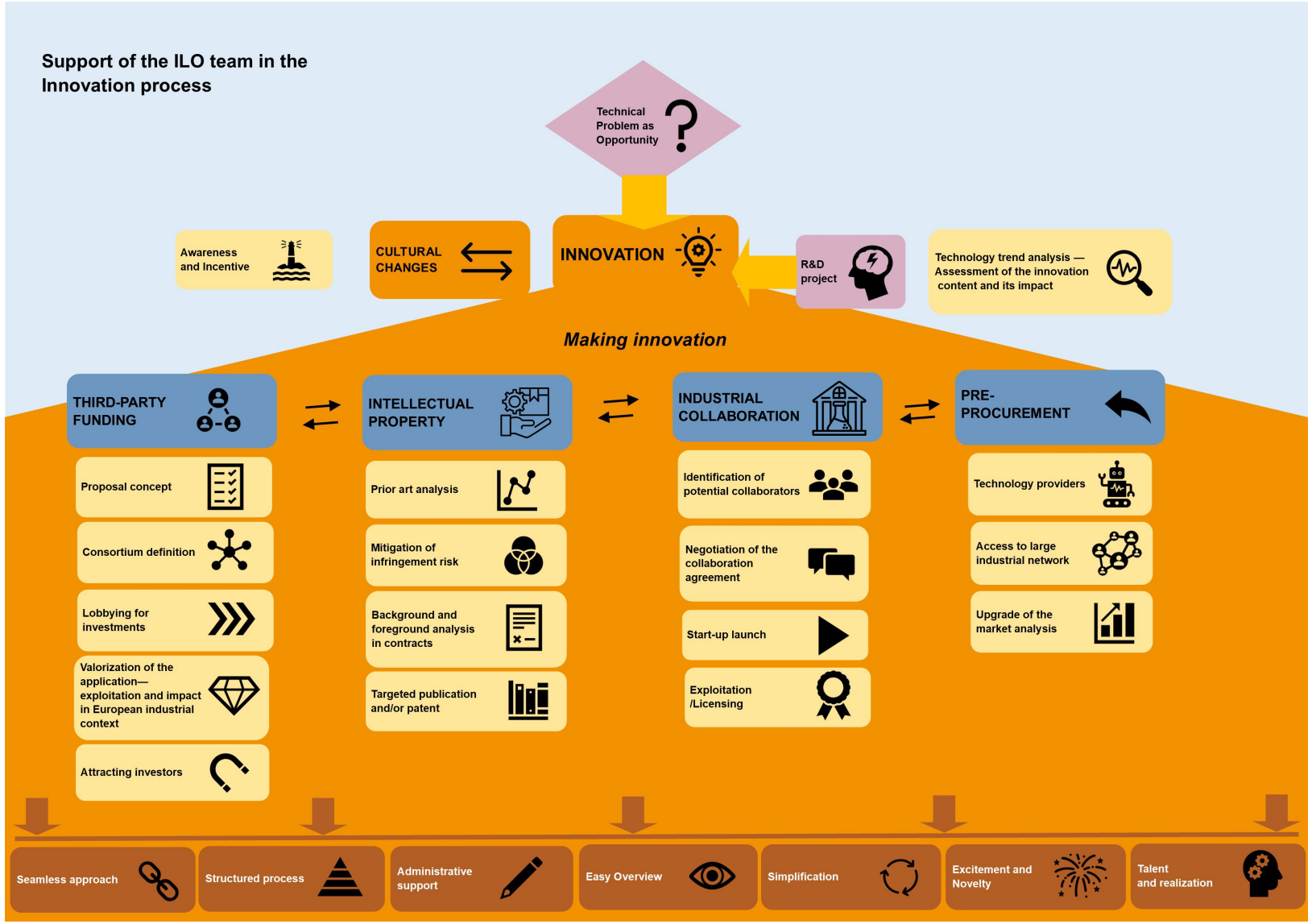
Light source development



The development of light source facilities has been faster than the increase in computer processing capacity (i.e., Moore's Law)

X-ray free-electron lasers worldwide

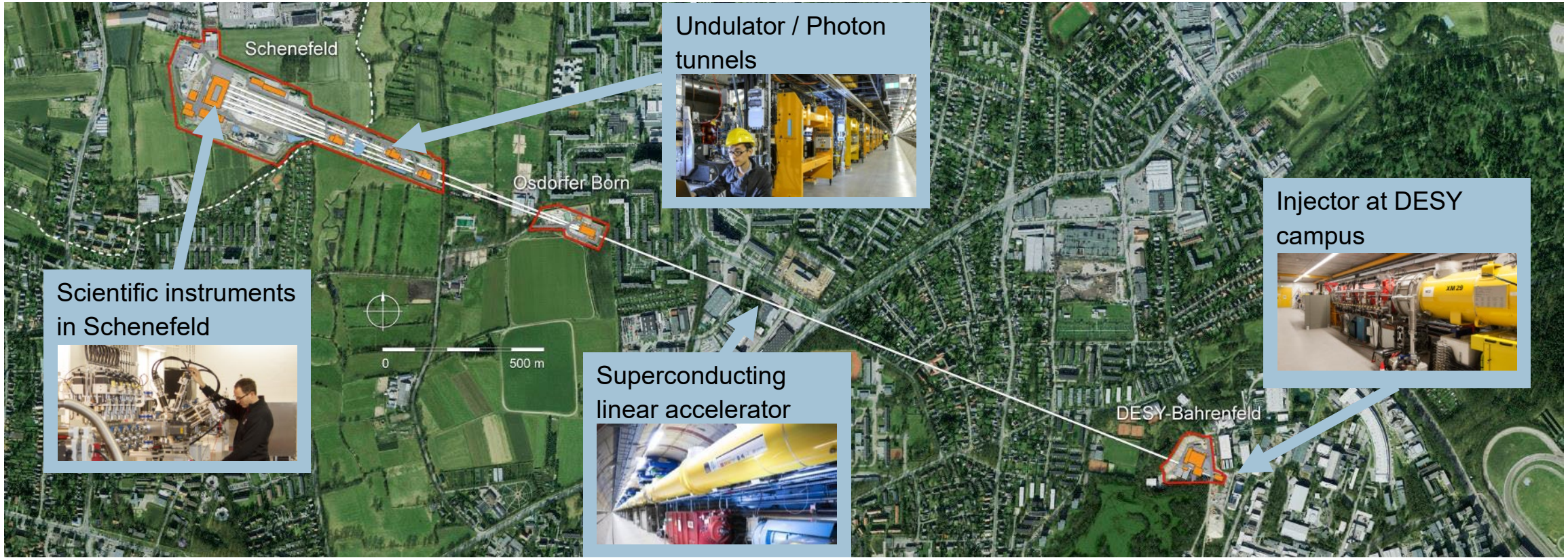
Project	FLASH	LCLS CuRF (USA)	LCLS-II SCRF (USA)	SACLA (Japan)	European XFEL	SwissFEL (CH)	PAL-XFEL (S. Korea)	SHINE (China)	FERMI (Italy)
Max. electron energy (GeV)	1.35	15	5.0	8.5	17.5	6.2	10	8	1.55 GeV
Wavelength range (nm)	3.4-90	0.05–5.0	0.25–5.0	0.06–0.3 /8-30	0.05–4.7	0.1–7	0.06–5.0	0.05–3.1	4-100 (1.7-4)
Photons/pulse	~10^{11}-10^{14}	5 x 10^{13}	0.5 - 5 x10^{12}	~5 x 10^{11}	~10^{12} (typical at 12.4 keV)	5 x 10^{11} (HX) 1.2 x 10^{14} (SX)	10^{11}–10^{13}	10^{10}–10^{13}	3x10^{11}-10^{14} (~10^{7}-10^{8})
Peak brilliance	1 x 10^{31}	4x10^{34} (measured at 10 keV)	2 x 10^{33} (simulated at 1.25 keV)	~5 x 10^{33}	3 x 10^{33} (8.3 keV simulated at saturation without seeding)	1 x 10^{32}–1 x 10^{33}	1.3 x 10^{33}	1 x 10^{33}	2x10^{32}
Average brilliance		5 x 10^{22}	3x10^{25}		2 x 10^{24} (8.3 keV simulated at saturation without seeding)				
Pulses/second	8000	120	1 000 000	60	27 000	100	60	1 000 000	50
Experiment Stations (parallel Operation)	7(2)	9 (3)		7 (3)	7 (3)	5 (2)	3 (2) Instruments 7 (2)	10 (3)	6(2)
Date of first beam	2005	2009	2023	2011	2017	2016	2016	2025	2010


Support of the ILO team in the Innovation process
Technical Problem as Opportunity
Awareness and Incentive
CULTURAL CHANGES
INNOVATION
R&D project
Technology trend analysis — Assessment of the innovation content and its impact
Making innovation
THIRD-PARTY FUNDING
Proposal concept
Consortium definition
Lobbying for investments
Valorization of the application— exploitation and impact in European industrial context
Attracting investors
INTELLECTUAL PROPERTY
Prior art analysis
Mitigation of infringement risk
Background and foreground analysis in contracts
Targeted publication and/or patent
INDUSTRIAL COLLABORATION
Identification of potential collaborators
Negotiation of the collaboration agreement
Start-up launch
Exploitation /Licensing
PRE-PROCUREMENT
Technology providers
Access to large industrial network
Upgrade of the market analysis
Seamless approach
Structured process
Administrative support
Easy Overview
Simplification
Excitement and Novelty
Talent and realization

Outline

- General presentation of European XFEL
- Main description of the facility
- Highlights on typical technologies in the experimental hall
- Information about procurement procedures, hints on new internal procedures
- Technologies of interest

General layout of the European XFEL



3.4 km from Injector to Experimental Hall.

Injector (Hamburg - DESY)

SC-LINAC (1,9 Km; 17,5 GeV)

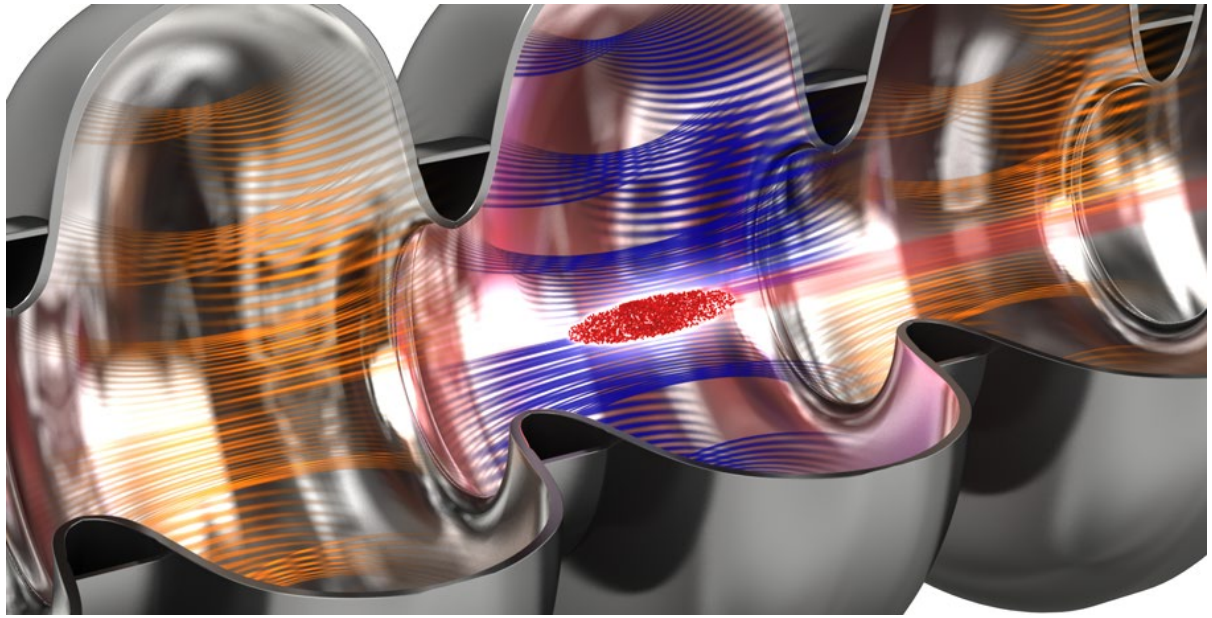
Undulators Sector

Undulators Sector

Photon Beamlines

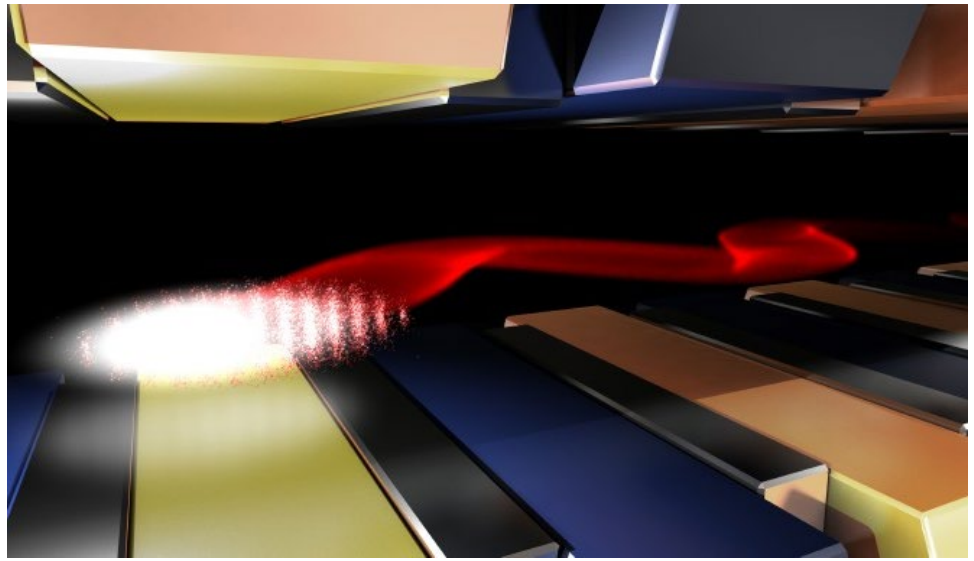
Instruments (Schenefeld)

Accelerator: electrons at close to light speed

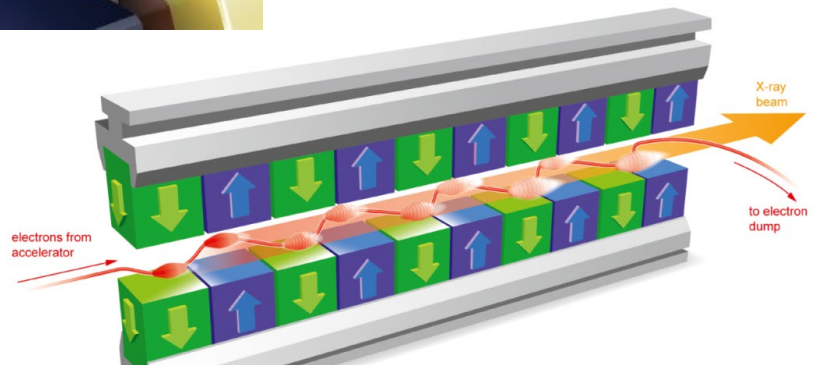


- Superconducting niobium cavities powered by intense radio frequency accelerate electrons
- Ninety-six accelerator modules over 1.7 km bring the electron bunch to near light speed and high energies

SASE (Self Amplified Spontaneous Emission) undulators: inducing electrons to emit X-ray light

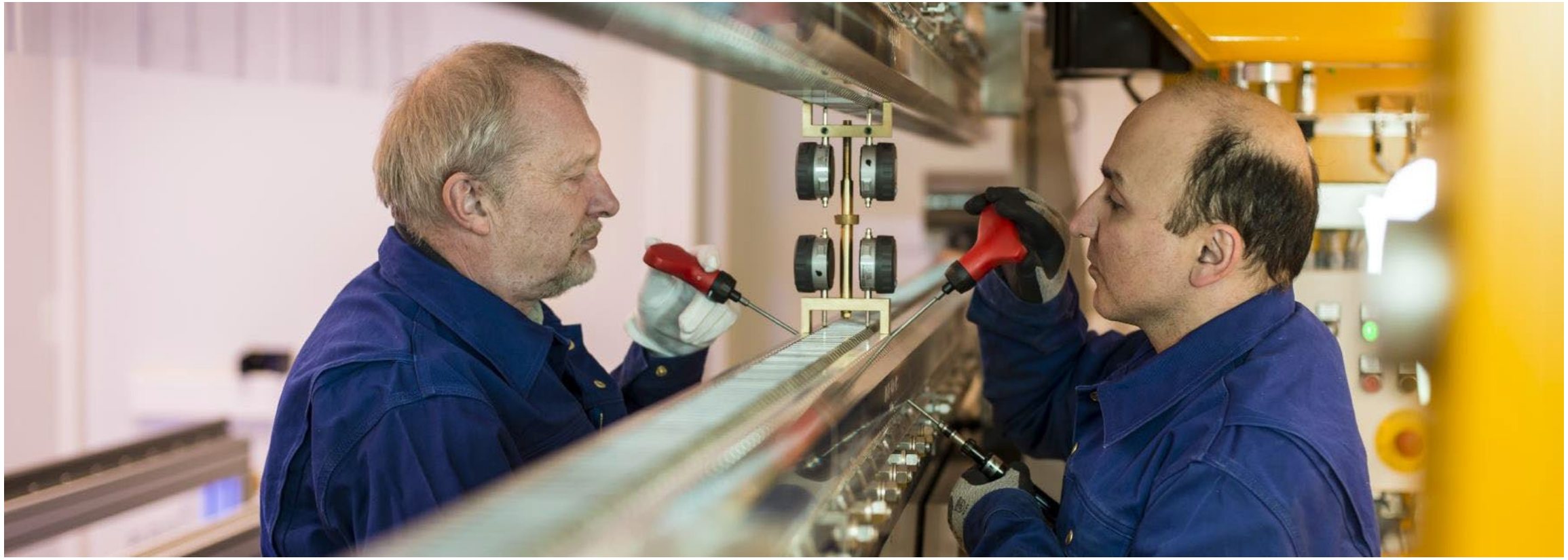


- Alternating magnetic fields cause electrons to take “slalom” course
- Electrons release X-rays with each turn
- SASE process builds intense, laser-like flashes

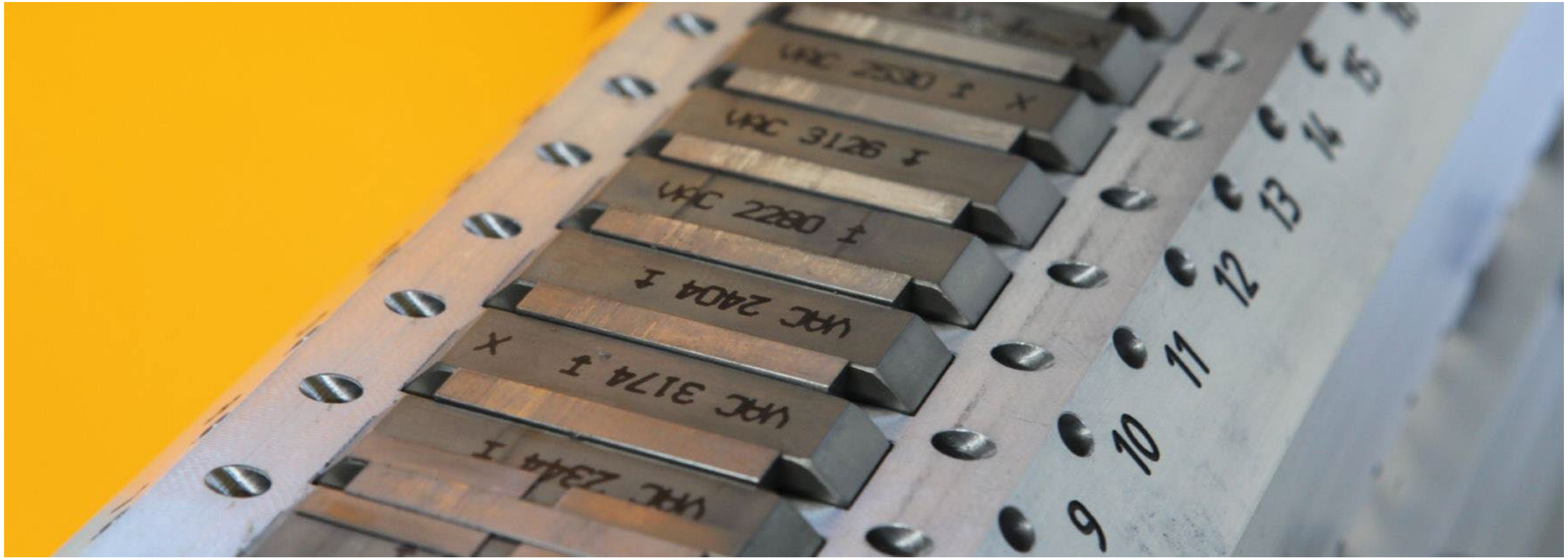


The European X-Ray Free-Electron Laser **Technical design report**
https://xfelbau.desy.de/technical_information/tdr/tdr/

Tuning undulators



Undulator magnets



Undulators in tunnel

Procurement regulation

Please have a look at
https://www.xfel.eu/organization/procurement/legal_and_regulatory_information/index_eng.html#laws_and_regulations

- Threshold EU international call for tender

The EU threshold for construction contracts was set at 5.35 M€ and for all other supply and service contracts at 221 k€

- Rules of Procedure for the award of public supply and service contracts below the EU thresholds

https://www.xfel.eu/sites/sites_custom/site_xfel/content/e35152/e46557/e47200/e47206/xfel_file47209/UVgO_Englisch_eng.pdf

- Procurement Ordinance

https://www.xfel.eu/sites/sites_custom/site_xfel/content/e35152/e46557/e47200/e47206/xfel_file86104/VgV-ordinance-award-of-public-contracts_eng.pdf

Call for tender

- The European XFEL GmbH is a public-equivalent body and is therefore subject to special legal regulations concerning the award of contracts and placement of purchase orders. This includes, for example:
  - **the VOB** ("Verdingungsordnung für Bauleistungen“, regulations for civil construction contracts),
  - **the VOF** (“Verdingungsordnung für freiberufliche Leistungen“, regulations for freelance and professional services contracts)
  - **the VOL** (“Vergabe- und Vertragsordnung für Leistungen“, regulations on contract awards for public supplies and services),

https://www.xfel.eu/organization/procurement/legal_and_regulatory_information/index_eng.html

- The award of contracts and placement of purchase orders fall under the responsibility of the Procurement Group

General Purchase Conditions

- Due to the fact that we are a goverment-funded organization, we are not allowed to accept other terms and conditions than these. Please read them carefully and include them as part of your public tender documentation.

https://www.xfel.eu/sites/sites_custom/site_xfel/content/e35152/e46557/e47200/e47202/xfel_file47204/EuXFEL_GeneralTermsConditions_01Oct2023_eng.pdf

General Purchase Conditions

If the delivery or service resulting from a works contract is carried out in accordance with the contractual conditions, it will be accepted. If a test run is agreed, the delivery or service is deemed accepted by means of a joint acceptance report after a flawless test run.

In addition, the Goods to be delivered must comply with the applicable safety regulations (e.g. EU Directive 2006/42 on machinery, EU Directive 2014/35 on the market of electrical equipment designed for use within certain voltage limits, EU Directive 2014/30 relating to electromagnetic compatibility, EU Directive 2014/68 on the market of pressure equipment, EU Directive 2011/65 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, German Product Safety Act (ProdSG - Act on making products available on the Market)and be provided with all prescribed markings (e.g. CE mark), declarations (e.g. declaration of conformity, declaration of incorporation) and documents (e.g. operating instructions, assembly instructions, safety data sheets). Protective devices, markings, declarations, and documents required according to such regulations shall be taken into account in the Contractor's calculation and shall be part of the scope of delivery, even if they are not requested separately by the Client.

General Purchase Conditions

The Contractor shall keep all images, drawings, calculations, and other documents and information (hereinafter referred to as “Confidential Information”) received for the execution of the Purchase order strictly confidential and to disclose them only to employees who have been obliged to treat them confidentially. Confidential Information may only be disclosed to third parties with the prior written consent of the Client, which must be granted in the event of proven judicial or statutory claims for disclosure. The obligation to maintain confidentiality shall also apply after the termination of this contract; it shall expire - unless otherwise agreed - five years after the conclusion of the contract or if and to the extent that the Confidential Information has become public domain.

Property rights

The Contractor is liable for ensuring that no third-party property rights are violated during the execution of the contract and during the delivery and use of the delivered item or service. Upon first written request, the Contractor shall indemnify the Client against any third-party claims arising from any property right infringements.

The Client is entitled to obtain the necessary authorization for delivery, commissioning, use, resale, etc. of the delivery item or service from the owner of such property rights at the Contractor’s expense if the Contractor is unable to obtain such rights, finally refuses such subsequent performance, or is in default with subsequent performance.

The Contractor shall grant the Client free-of-charge a non-exclusive and irrevocable license to all domestic and foreign property rights, applications for property rights, and inventions, insofar as they have arisen during the performance of this contract. Furthermore, the Contractor shall grant the Client free-of-charge an irrevocable and non-exclusive right to use all know-how and every innovation and improvement, insofar as these have arisen during the performance of this contract. The Client is entitled to transfer licenses and rights of use within the meaning of the above paragraph to its shareholders. This shall also apply beyond the term of this contract. The Contractor shall expressly agree the above rights with its subcontractors for the benefit of the Client.

General Purchase Conditions

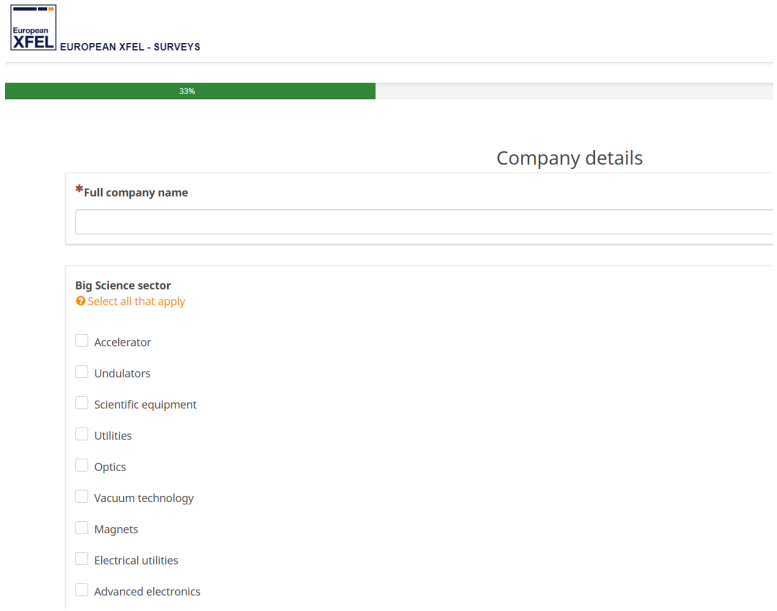
The Contractor shall, no later than two weeks after placing the Purchase order, notify the Client independently and in writing for each individual item of all information and subsequent changes thereto required by the Client for compliance with foreign trade and payments law in the case of export, import, and re-export, in particular:

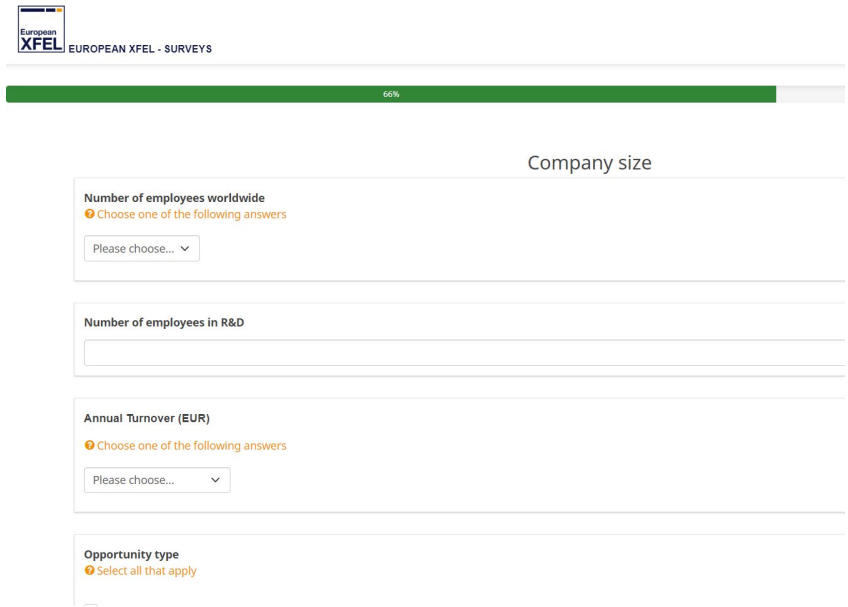
3.2. All applicable export list numbers, in particular in accordance with Annex AL to the German Foreign Trade and Payments Regulation (AWV) or comparable list positions of relevant export lists including the "Export Control Classification Number" in accordance with the "US Commerce Control List" (ECCN), if the Goods are subject to the "US Export Administration Regulations" (EAR);

3.5. All information of the Contractor required by the Client for the fulfillment of its obligations under the EU Regulation 2023/956 establishing a carbon border adjustment mechanism; and

Innovation procurement workflow

Technology provider contact database





https://in.xfel.eu/thesurvey/index.php/782712

Outline

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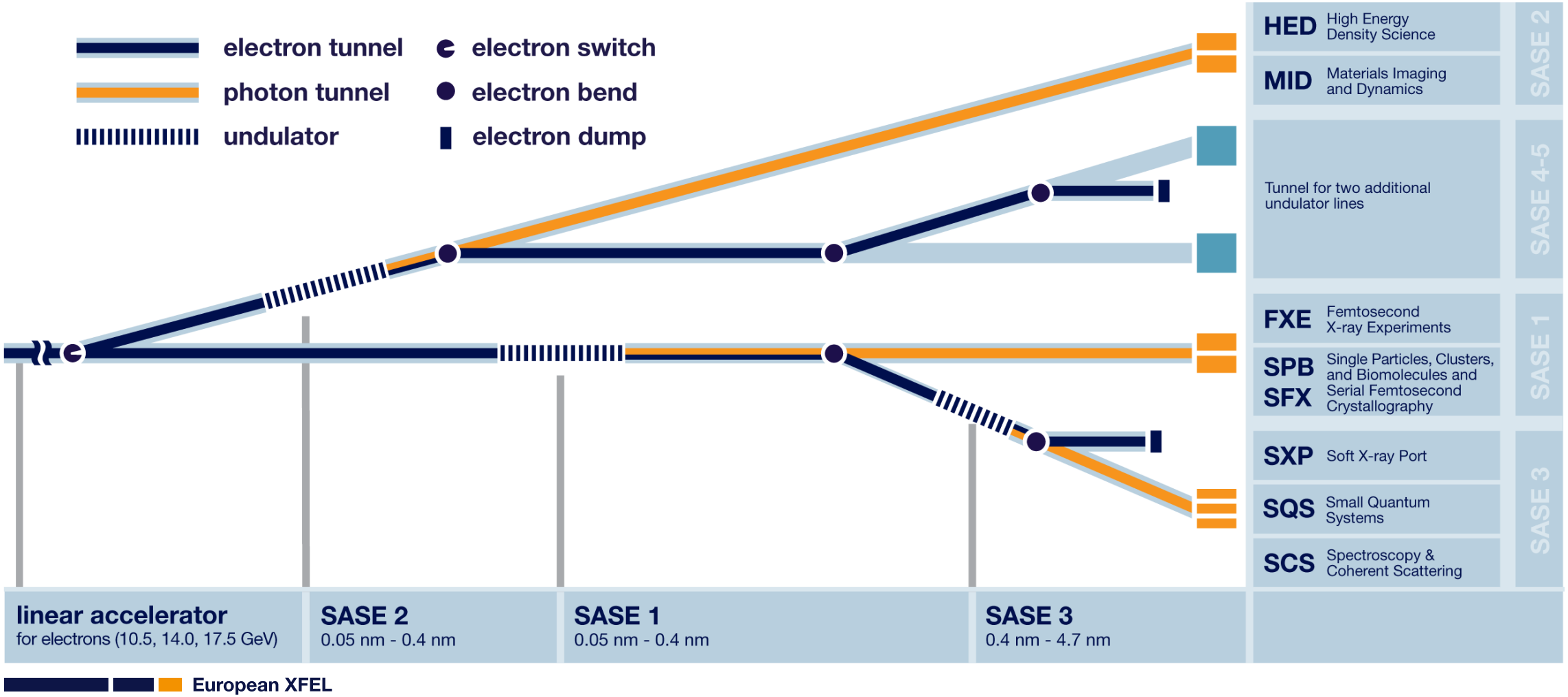
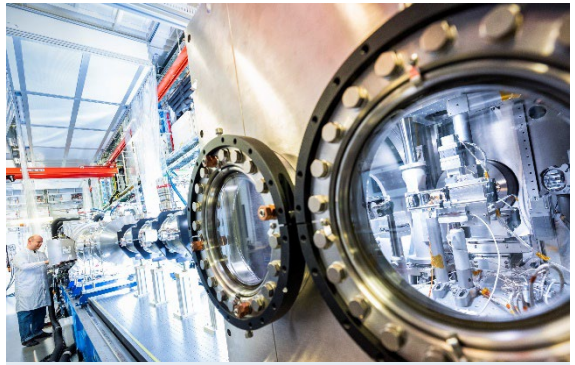
Beamline layout and experiment stations

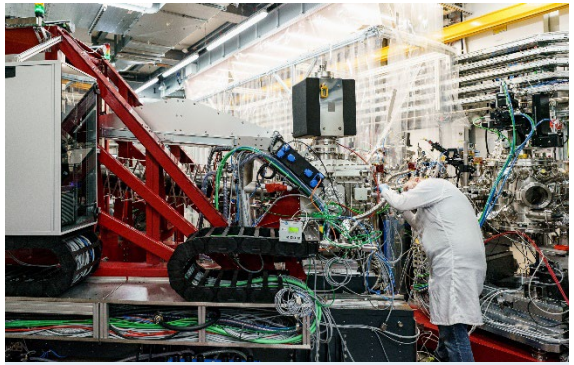


Seven scientific instruments

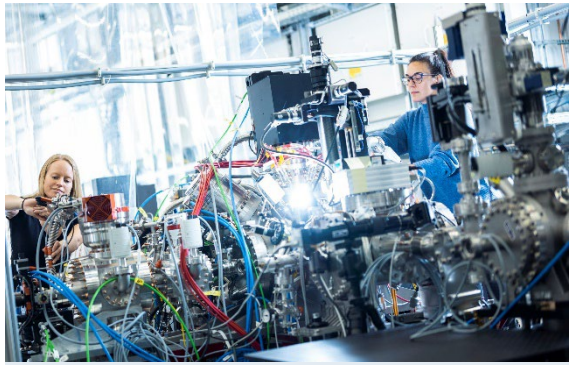
FXE (start Sep 2017)



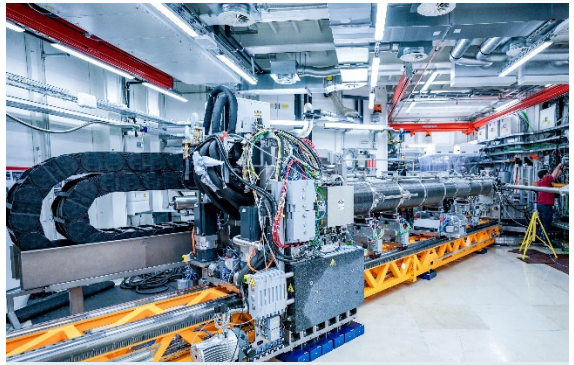
SPB/SFX (start Sep 2017)



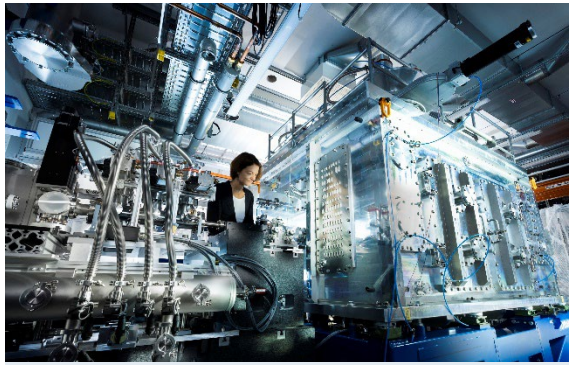
SCS (start Nov 2018)



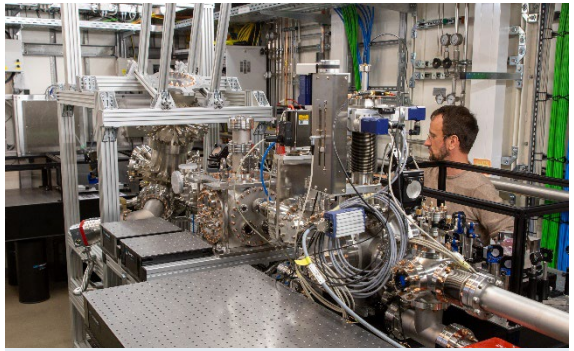
SQS (start Nov 2018)



MID (start Apr 2019)



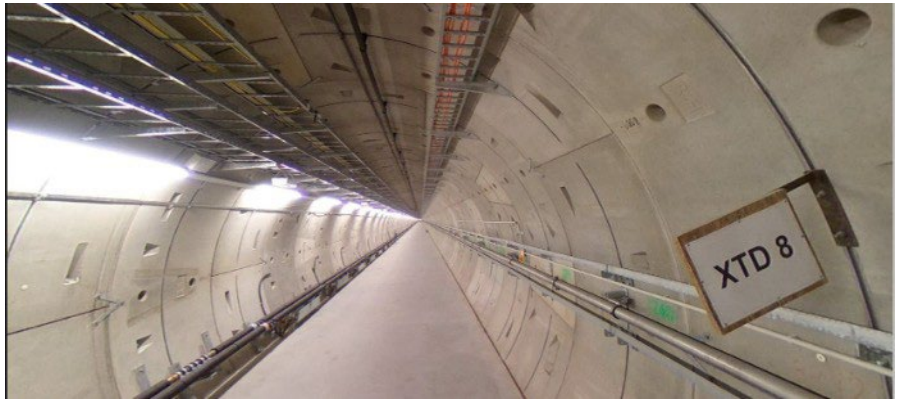
HED (start May 2019)

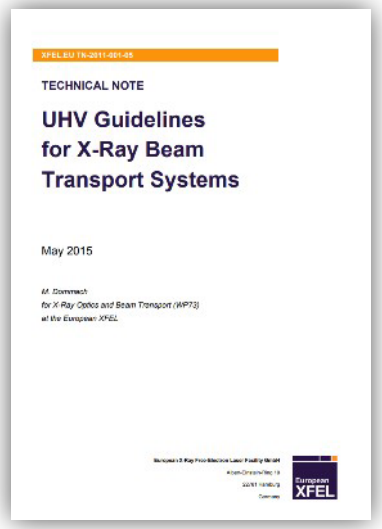


SXP (start summer 2023)

Photon Beam Transport System

- According to XFEL UHV Guidelines.
- Outsourced manufacturing and cleaning.
- “Particle free“ specifications (ISO Class 5/6).
- Sectorization & Mobile clean tents.
- In-situ conditioning (specific cases): wet-cleaning, baking, plasma cleaning…
- Hundreds of meters beampipe (flanged and in-situ orbital-welded sectors)
- Standard vacuum components:
  - Pumping Stations
  - Beamline Pumping equipment (mechanical, SIP’s, NEG’s)
  - Controller for pumps, gauges…
  - Gauges, RGA‘s,…
- PLC Control system (racks, terminals, interfaces).
  - PLC terminals
  - Power supplies, connectors, cables
  - Controller for pumps, gauges…




TECHNICAL NOTE

UHV Guidelines for X-Ray Beam Transport Systems

May 2015

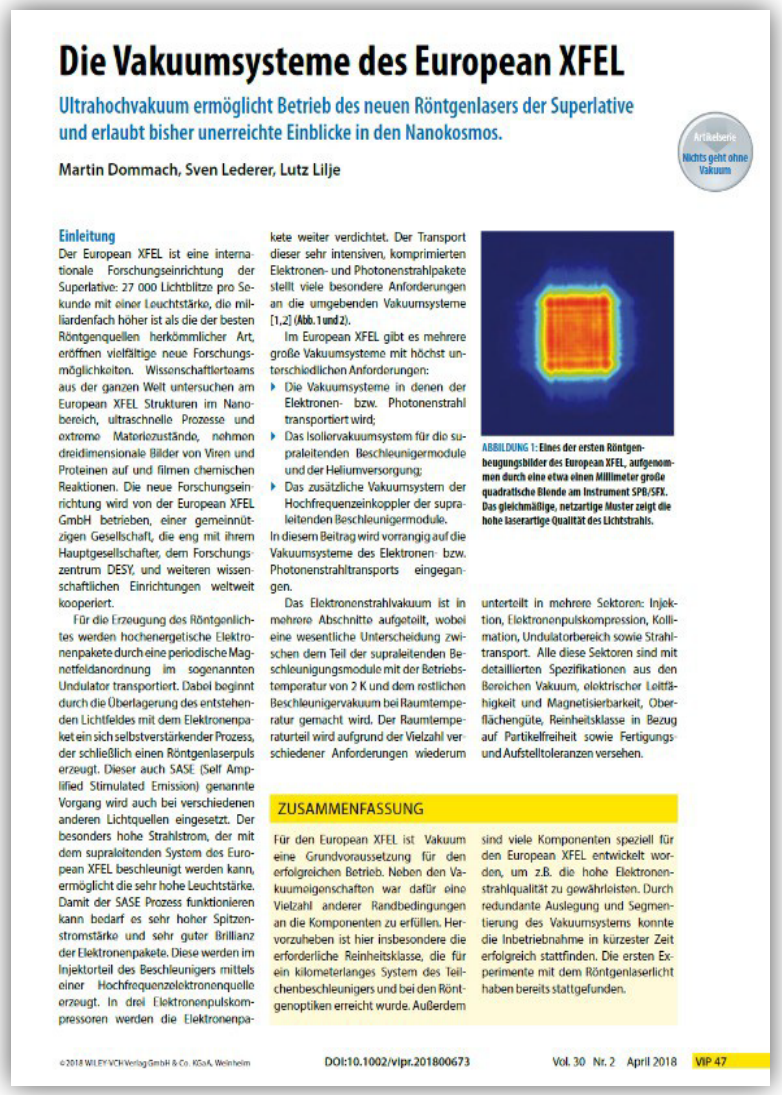
Some „sizing“ numbers for vacuum…

Construction phase (2011-2017)

- Accelerator warm vacuum system: 6 M€
- Accelerator cold vacuum system : 5 M€
- Photon beamlines (warm) vacuum system: 8 M€

Operation-related averaged procurement(*)

- Accelerator cold vacuum system: 250 k€/year
- Accelerator warm vacuum system: 500 k€/year
- Photon beamlines (warm) vacuum system: 600 k€/year



Die Vakuumsysteme des European XFEL

Ultrahochvakuum ermöglicht Betrieb des neuen Röntgenlasers der Superlative und erlaubt bisher unerreichte Einblicke in den Nanokosmos.

Martin Dommach, Sven Lederer, Lutz Lilje

Einleitung

Der European XFEL ist eine internationale Forschungseinrichtung der Superlative: 27 000 Lichtblitze pro Sekunde mit einer Leuchtstärke, die milliardenfach höher ist als die der besten Röntgenquellen herkömmlicher Art, eröffnen vielfältige neue Forschungsmöglichkeiten. Wissenschaftlerteams aus der ganzen Welt untersuchen am European XFEL Strukturen im Nanobereich, ultraschnelle Prozesse und extreme Materiezustände, nehmen dreidimensionale Bilder von Viren und Proteinen auf und filmen chemischen Reaktionen. Die neue Forschungseinrichtung wird von der European XFEL GmbH betrieben, einer gemeinnützigen Gesellschaft, die eng mit ihrem Hauptgesellschafter, dem Forschungszentrum DESY, und weiteren wissenschaftlichen Einrichtungen weltweit kooperiert.

Für die Erzeugung des Röntgenlichtes werden hochenergetische Elektronenpakete durch eine periodische Magnetfeldanordnung im sogenannten Undulator transportiert. Dabei beginnt durch die Überlagerung des entstehenden Lichtfeldes mit dem Elektronenpaket ein sich selbstverstärkender Prozess, der schließlich einen Röntgenlaserpuls erzeugt. Dieser auch SASE (Self Amplified Stimulated Emission) genannte Vorgang wird auch bei verschiedenen anderen Lichtquellen eingesetzt. Der besonders hohe Strahlstrom, der mit dem supraleitenden System des European XFEL beschleunigt werden kann, ermöglicht die sehr hohe Leuchtstärke. Damit der SASE Prozess funktionieren kann bedarf es sehr hoher Spitzenstromstärke und sehr guter Brillianz der Elektronenpakete. Diese werden im Injektorteil des Beschleunigers mittels einer Hochfrequenzelektronenquelle erzeugt. In drei Elektronenpulskompressoren werden die Elektronenpakete weiter verdichtet. Der Transport dieser sehr intensiven, komprimierten Elektronen- und Photonenstrahlpakete stellt viele besondere Anforderungen an die umgebenden Vakuumsysteme [1,2] (Abb. 1 und 2).

Im European XFEL gibt es mehrere große Vakuumsysteme mit höchst unterschiedlichen Anforderungen:

- Die Vakuumsysteme in denen der Elektronen- bzw. Photonenstrahl transportiert wird;
- Das Isoliervakuumsystem für die supraleitenden Beschleunigermodule und der Heliumversorgung;
- Das zusätzliche Vakuumsystem der Hochfrequenzeinkoppler der supraleitenden Beschleunigermodule.

In diesem Beitrag wird vorrangig auf die Vakuumsysteme des Elektronen- bzw. Photonenstrahltransports eingegangen.

Das Elektronenstrahlvakuum ist in mehrere Abschnitte aufgeteilt, wobei eine wesentliche Unterscheidung zwischen dem Teil der supraleitenden Beschleunigungsmodule mit der Betriebstemperatur von 2 K und dem restlichen Beschleunigervakuum bei Raumtemperatur gemacht wird. Der Raumtemperaturteil wird aufgrund der Vielzahl verschiedener Anforderungen wiederum unterteilt in mehrere Sektoren: Injektion, Elektronenpulskompression, Kollimation, Undulatorbereich sowie Strahltransport. Alle diese Sektoren sind mit detaillierten Spezifikationen aus den Bereichen Vakuum, elektrischer Leitfähigkeit und Magnetisierbarkeit, Oberflächengüte, Reinheitsklasse in Bezug auf Partikelfreiheit sowie Fertigungs- und Aufstelltoleranzen versehen.

ABBILDUNG 1: Eines der ersten Röntgenbeugungsbilder des European XFEL, aufgenommen durch eine etwa einen Millimeter große quadratische Blende am Instrument SPB/SFX. Das gleichmäßige, netzartige Muster zeigt die hohe laserartige Qualität des Lichtstrahls.

ZUSAMMENFASSUNG

Für den European XFEL ist Vakuum eine Grundvoraussetzung für den erfolgreichen Betrieb. Neben den Vakuumeigenschaften war dafür eine Vielzahl anderer Randbedingungen an die Komponenten zu erfüllen. Hervorzuheben ist hier insbesondere die erforderliche Reinheitsklasse, die für ein kilometerlanges System des Teilchenbeschleunigers und bei den Röntgenoptiken erreicht wurde. Außerdem sind viele Komponenten speziell für den European XFEL entwickelt worden, um z.B. die hohe Elektronenstrahlqualität zu gewährleisten. Durch redundante Auslegung und Segmentierung des Vakuumsystems konnte die Inbetriebnahme in kürzester Zeit erfolgreich stattfinden. Die ersten Experimente mit dem Röntgenlaserlicht haben bereits stattgefunden.

DOI:10.1002/vipr.201800673 Vol. 30 Nr. 2 April 2018 VIP 47

https://onlinelibrary.wiley.com/doi/full/10.1002/vipr.201800673

(*)Estimations derived from the first years of operation

Hybrid permanent magnet undulators at European XFEL

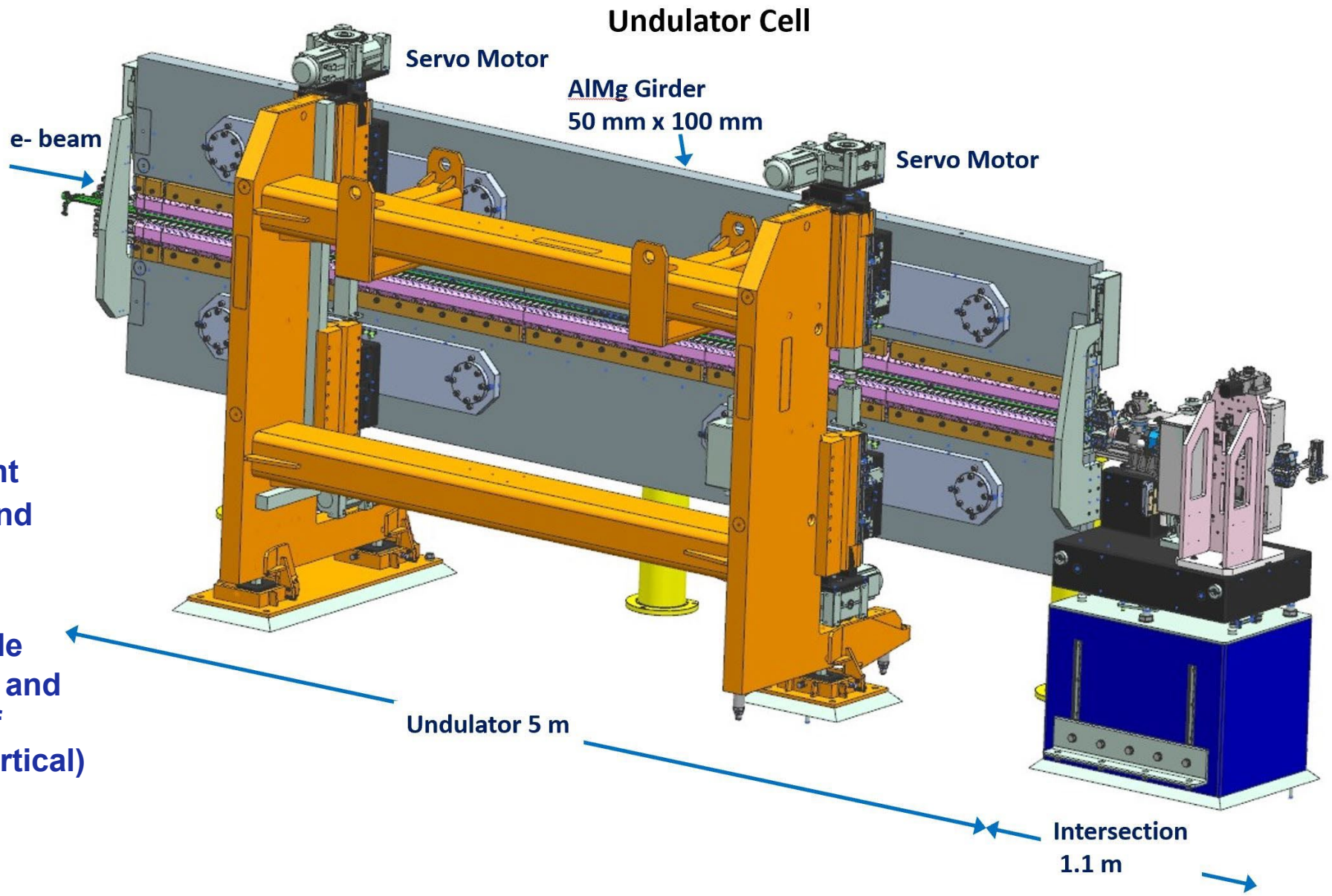
Table 1
Specifications for the undulator segments of the EuXFEL.

The operational ranges for gap and K parameter match user requirements (Altarelli *et al.*, 2006). Only inside are all specifications strictly fulfilled. Magnetic tuning was always performed at the tuning gap to limit gap dependence of magnetic properties, see discussion of Fig. 4.

	SASE1 / SASE2	SASE3
Undulator type	U40	U68
Period length (mm)	40	68
Segment length (m)	5	5
Total number of poles	248	146
Magnetically active poles	246	144
Number of ending poles	3	3
Operational gap range (mm)	10–20	10–25
Operational K-parameter range	1.65–3.9	4–9
Maximum peak field @ 10 mm (T)	1.11	1.66
Tuning gap (mm)	14	16
Maximum gap (mm)	200	200
Maximum phase jitter (°)	≤8	≤8
Maximum 1st B_y field integral (T mm)	±0.15	±0.15
Maximum 1st B_x field integral (T mm)	±0.15	±0.15
RMS of 2nd B_y integral (T mm^2)	<100	<210
RMS of 2nd B_x integral (T mm^2)	<100	<100
Radiation wavelength range (nm)	0.05–0.4	0.4–5.2
Number of segments in system	35	21
System length (m)	205	121

S. Abeghyan et al., J. Synchrotron Rad. (2019). 26, 302–310

Typical undulator cell at European XFEL



European XFEL planar undulators for SASE1/2/3 are hybrid permanent magnet undulators using NdFeB and soft iron poles made of cobalt iron

The beam vacuum chamber is made of extruded aluminum-magnesium and has an elliptical beam stay clear of 15 mm (horizontal) and 8.6 mm (vertical)

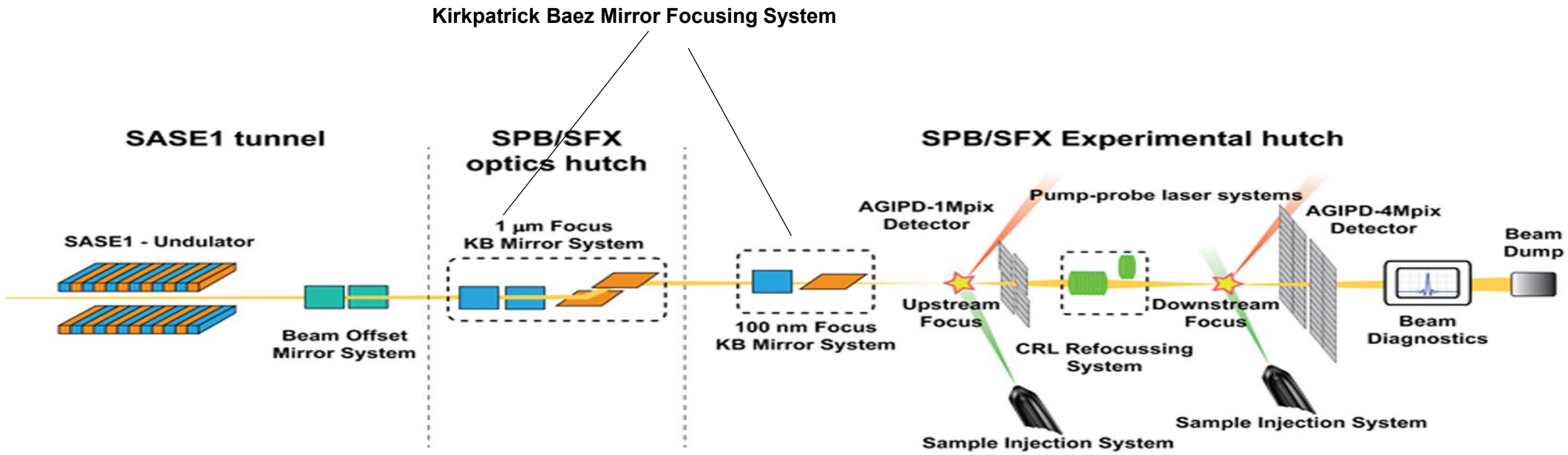
Components for SCU development at EuXFEL

- Part of the SCU module:
  - Cryocoolers
  - Power supplies
    - ► Correctors and phase shifter: ±10 A, 10 V
    - ► Main coils: 400-1000 A, 10-20 V
    - as small as possible to fit in the tunnel
  - Vacuum pumps
  - CAM movers
- Elements for intersections:
  - Quadrupoles, Quadrupole movers, Air coils
  - Granite stone, alignment mechanism
  - Absorbers, BPMs, BLMs
  - Phase shifters
  - RF bellows, RF valve
- SUNDAE1/2
  - CuBe wires
  - Vacuum pumps
  - Hall probes + readout and current source
  - Temperature sensors and monitors
  - In vacuum (UHV) motors and linear stages
  - …
- Advanced SCU coils
  - NbTi wires, HTS tapes
  - Precisely machined iron few tenths μm
  - Epoxy, kapton
  - …

SPB/SFX Instrument

https://www.xfel.eu/facility/instruments/spb_sfx/science_programme/index

- Diffractive imaging of micrometre-scale and smaller objects, at atomic or near-atomic resolution.
- Structural dynamics on the millisecond to femtosecond timescale.
- It consists of two experiment endstations (upstream and downstream),

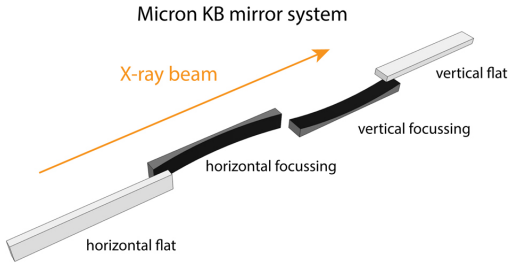


SPB/SFX Instrument

https://www.xfel.eu/facility/instruments/spb_sfx/science_programme/index

MHE	Micron horizontal elliptical KB
Deflection	Horizontal (negative x)
Source—optic (centre) distance	894.779 m
Optic (centre) focus distance	24.005 m
Saggital radius (minimum)	10 km

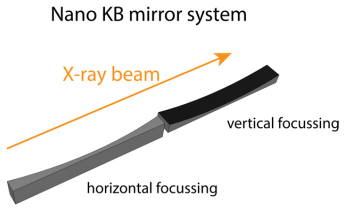
Controlled motion (relative to incident beam)	Minimum	Maximum	Resolution
X	−2 mm	+10 mm	<1 μm
Y (coating selection)	−15 mm	+15 mm	<1 μm
θ_y (pitch)	−0.5 mrad	+5.5 mrad	<20 nrad



Kirkpatrick Baez Mirror Focusing System

NHE	Nanometer horizontal elliptical KB
Deflection	Horizontal (positive x)
Source—optic (centre) distance	915.484 m
Optic (centre) focus distance	3.3 m
Saggital radius (minimum)	10 km

Controlled motion (relative to incident beam)	Minimum	Maximum	Resolution
X	−10 mm	+5 mm	<1 μm
Y (coating selection)	−15 mm	+15 mm	<1 μm
Z (astigmatism correction)	−5 mm	+5 mm	<1 μm
θ_y (pitch)	−0.5 mrad	+5.5 mrad	<20 nrad

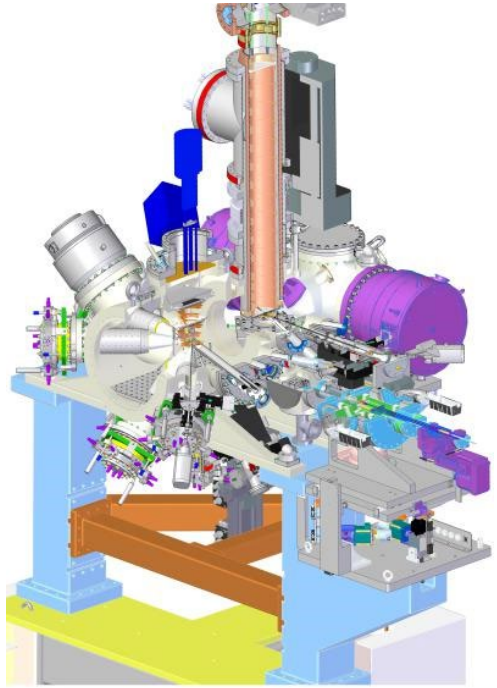


J. Opt. 18 (2016) 074011
https://iopscience.iop.org/article/10.1088/2040-8978/18/7/074011

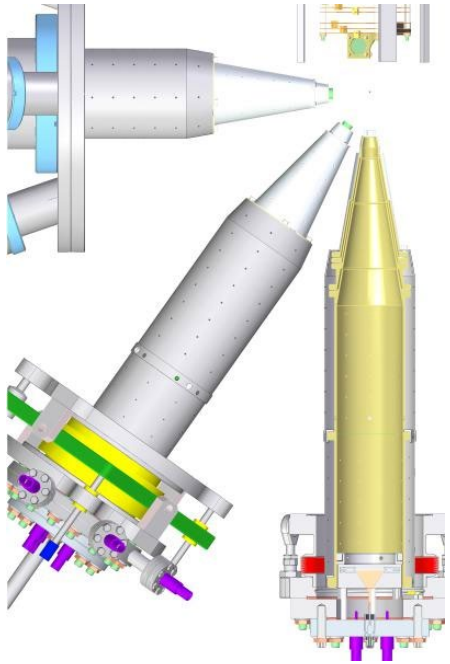
SQS Instrument

https://www.xfel.eu/facility/instruments/sqs/index_eng.html

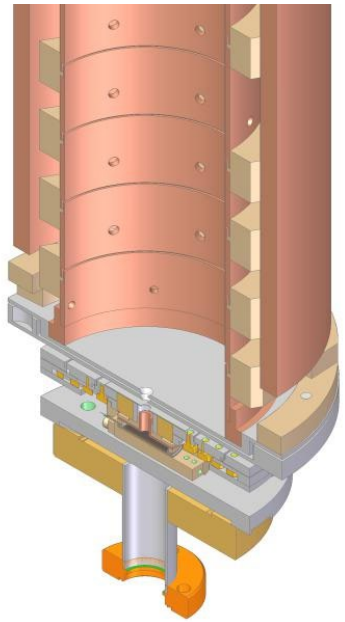
Investigations of fundamental processes of light-matter interaction in the soft X-ray wavelength regime.



Atomic-like Quantum Systems (AQS)
quantum systems, i.e. free atoms or small molecules.
The alignment of the AQS chamber with respect to the FEL beam is realized with a set-up enabling translation (50 mm) and rotational movements of the
vacuum chamber with a precision of less than 0.5 µm.



Electron Time-Of-Flight (eTOF)
In combination of fast digitizer, (till 4.5 MHz)
Detector MCP, 450 ps timing resolution

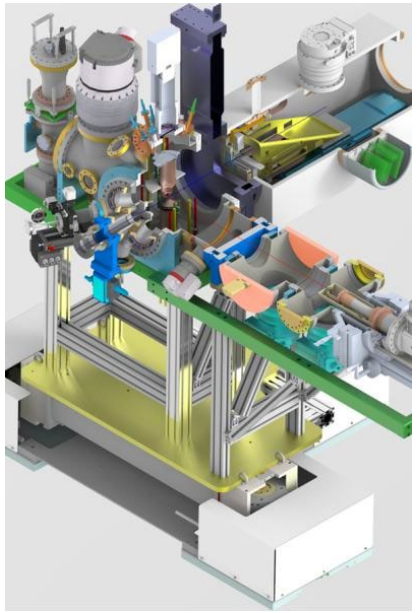


Magnetic Bottle Electron Spectrometer (MBES)
Time of flight spectroscopy

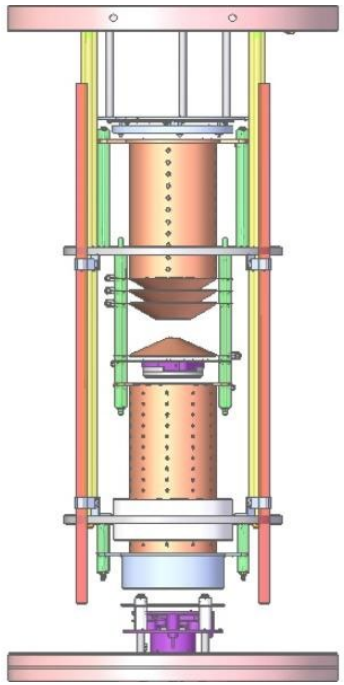
SQS Instrument

https://www.xfel.eu/facility/instruments/sqs/index_eng.html

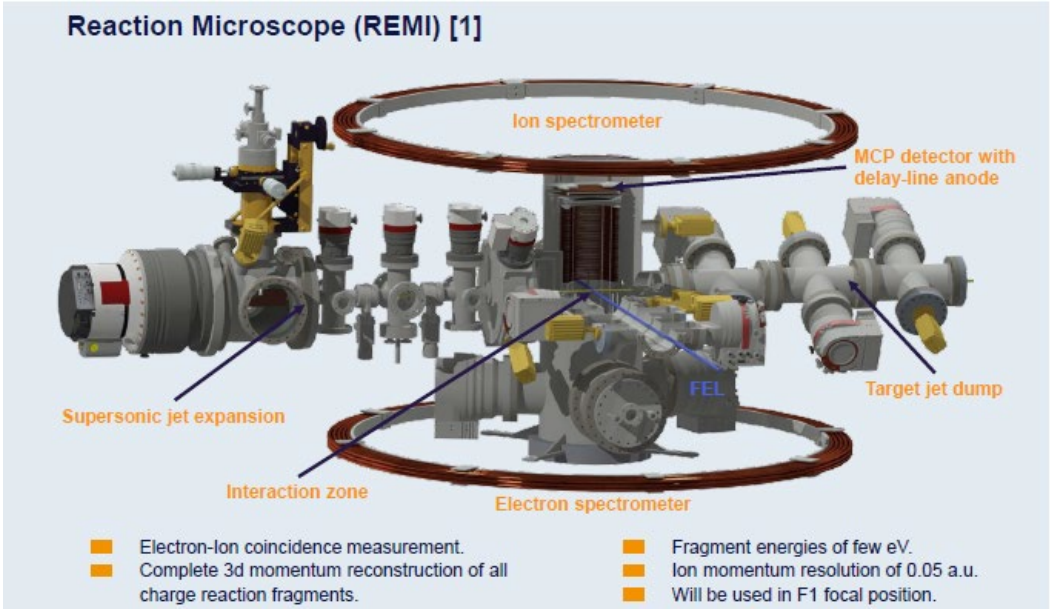
- Investigations of fundamental processes of light-matter interaction in the soft X-ray wavelength regime.



Nano-sized Quantum Systems (NQS)
Nanoparticle The vacuum conditions in the NQS chamber are mainly limited by the imaging detector and are at best about 10^{-10} mbar



Ion Time-Of-Flight (iTOF- Wiley-McLaren design)
Velocity Map Imaging (VMI) spectrometer



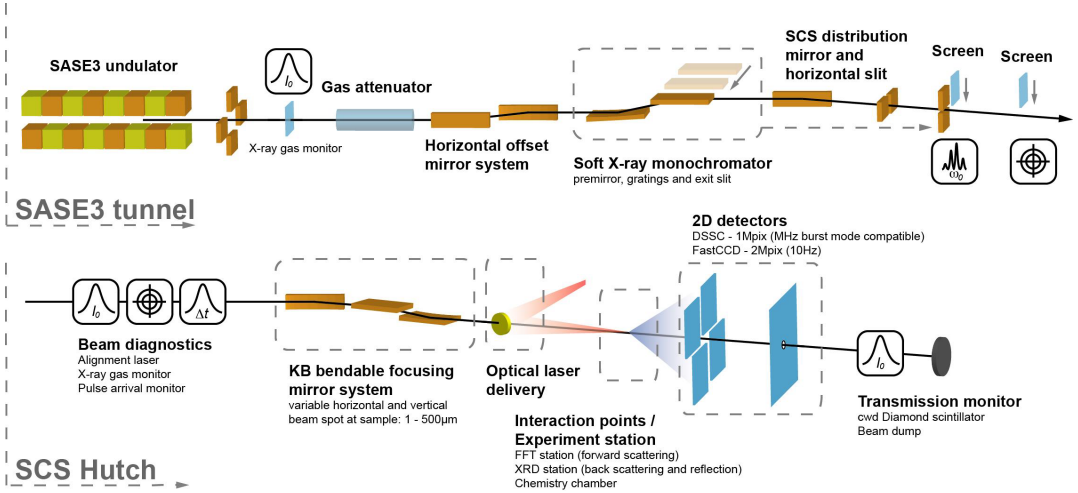
A Reaction Microscope (REMI) ion and electron momentum imaging experiments in the gas phase:
a three-stage supersonic gas jet
four piezo-controlled apertures, nozzle 5 µm to 300 µm, temperatures from 5 K to 450 K

SCS Instrument

https://www.xfel.eu/facility/instruments/scs/index_eng.html

- Enables time-resolved experiments to unravel the electronic and structural properties of complex materials, molecules, and nanostructures in their fundamental space-time dimensions.

- The SCS instrumentation is equipped with:
  - the FFT experiment station (forward-scattering and transmission geometries)
  - the XRD experiment station (back- scattering and reflection geometries).
  - 2D array detectors, the 1MPix DSSC detector (4.5 MHz rep rate) and the 2Mpix FastCCD detector (10Hz), for coherent x-ray diffraction experiments
  - A high-resolution Resonant Inelastic X-ray Scattering (RIXS) spectrometer
  - a chemistry chamber station for liquid jets will be available in addition to the XRD experiment station.

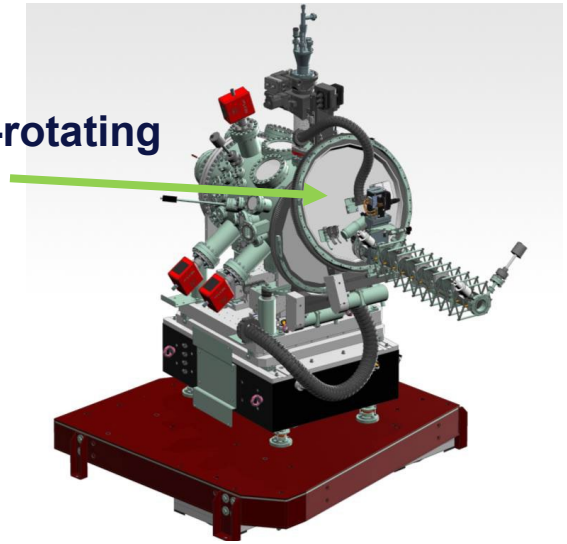


Parameter	Current Value
Photon energy	0.5 keV – 3.0 keV
X-ray pulse duration	10-25 fs fwhm
X-ray pulse stretching (Expected durations based on Monochromator)	80-150 fs (mono HR) 30-50 fs (mono LR)
X-ray polarization	Linear horizontal (𝝅-polarization) Linear vertical and circular polarizations may become available during 2022
X-ray focal spot size at sample	5 µm (hor & ver) tunable up to 500 µm
Mono resolving power	10.000 (HR) 3.000 (LR)
Photon energy hRIXS	0.5 keV – 1.4 keV
Combined resolving power (Monochromator & hRIXS)	Up to 10.000

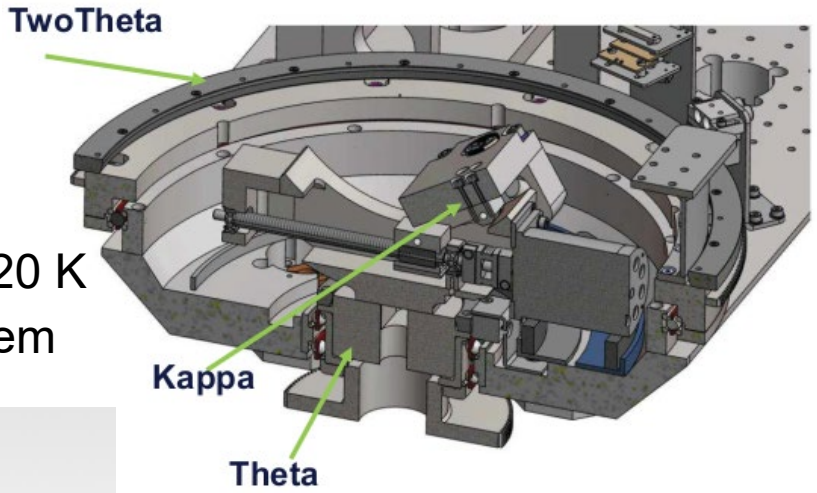
SCS Instrument

https://www.xfel.eu/facility/instruments/scs/index_eng.html

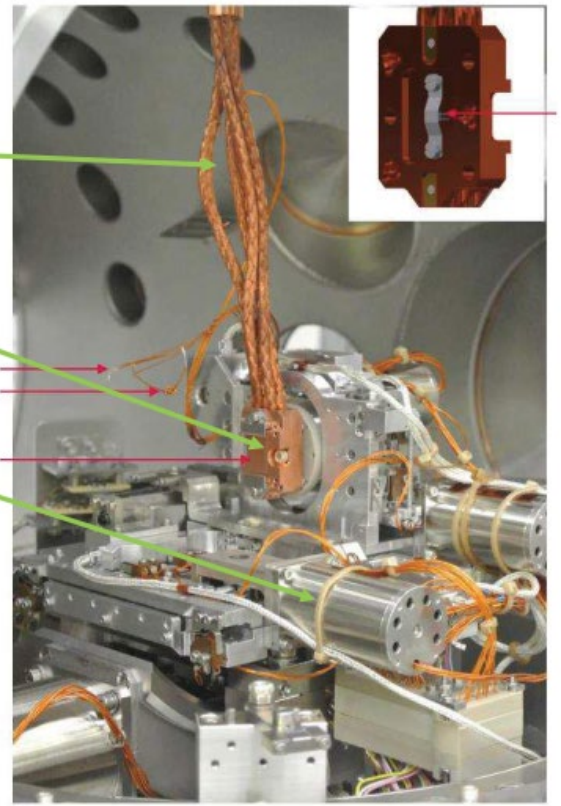
- Triple-rotating flange to change scattering angle
  - Sample: 6 DOF
  - UHV (*p*< 10-9mbar)
  - Temperatures: RT – 20 K
  - Sample transfer system



X-ray diffractormeter Inner Mechanics



Motion	Range	Repeatibility
TwoTheta	± 180 deg	< 1 µrad
Theta	± 180 deg	< 1 µrad
Kappa	± 30 deg	< 1 µrad
Azimuth	± 90 deg	< 0.0002 deg
X	± 5 mm	0.5 µm
Y	± 5 mm	0.5 µm
Z	± 5 mm	0.5 µm



https://www.xfel.eu/sites/sites_custom/site_xfel/content/e35165/e46561/e46895/e146931/xfel_file146932/WebinarhRIXS_2021Oct21_final_eng.pdf

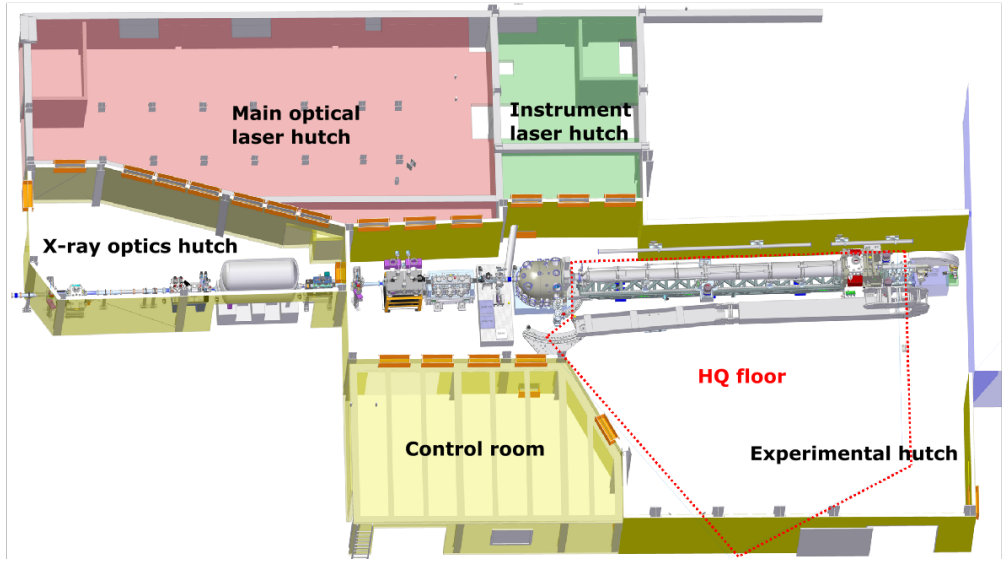
MID Instrument

https://www.xfel.eu/facility/instruments/mid/index_eng.html

- The scope of the MID instrument are material science experiments. The scientific applications reach from condensed matter physics, studying for example glass formation and magnetism, to soft and biological material, such as colloids, cells and viruses.

- Special Optics:
  - 2 monochromators (Si111 and Si220)
  - 2 compound refractive lens (CRL) transfocator units
  - Split and delay line
  - High-energy Laue monochromator (optional)
  - Mirror in experiment hutch (for grazing incidence liquid scattering)

- Equipment:
  - Multipurpose chamber
  - SAXS/WAXS geometries with long horizontal detector arm
  - Small vertical WAXS setup
  - Single-pulse X-ray diagnostics
  - Different detector systems (AGIPD, FastCCD)
  - Optical pump laser source



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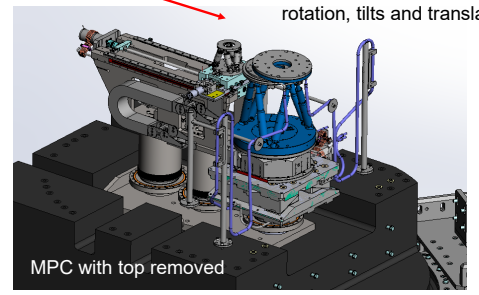
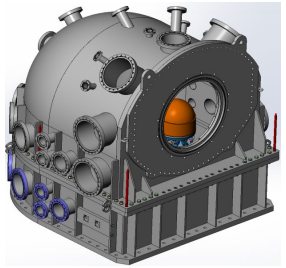
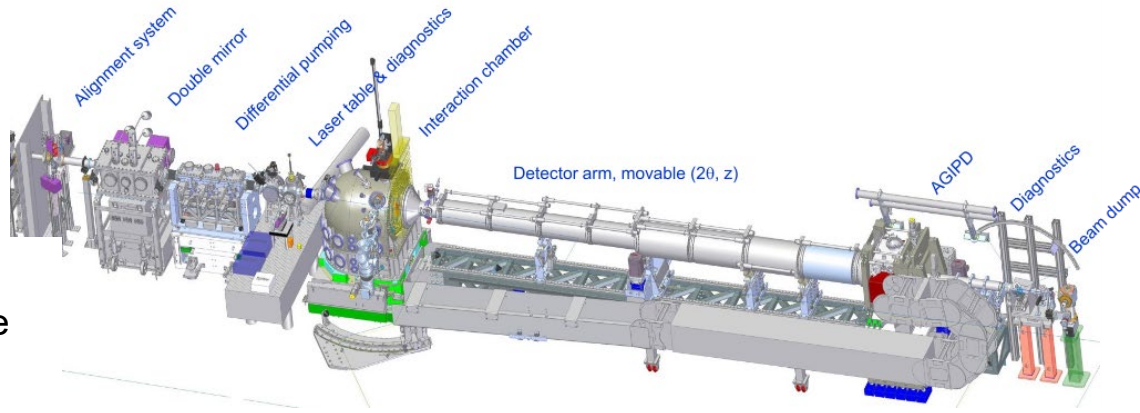




MPC operates under vacuum, windowless config.
Possibility to work without lid (in air or He bag)

Sample environment
- 10 Hz solid sample scanner
- Pulsed B field (Up to ~15T, 1 ms pulse)
- Liquid jet
- ….



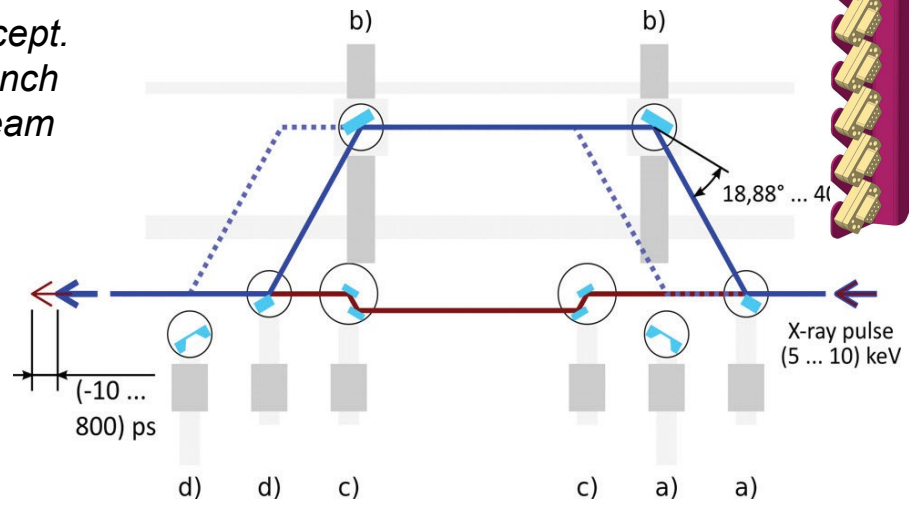
Several different detector configurations can be achieved at the MID instrument. The option to operate a very long (8 m) horizontal scattering arm is a special feature of the instrument. The horizontal arm can move continuously in an angular range from 0° to 50°.
A floor with a flatness (1mm in 10 m) has been installed

MID Instrument

https://www.xfel.eu/facility/instruments/mid/index_eng.html

Split and delay line (SDL)

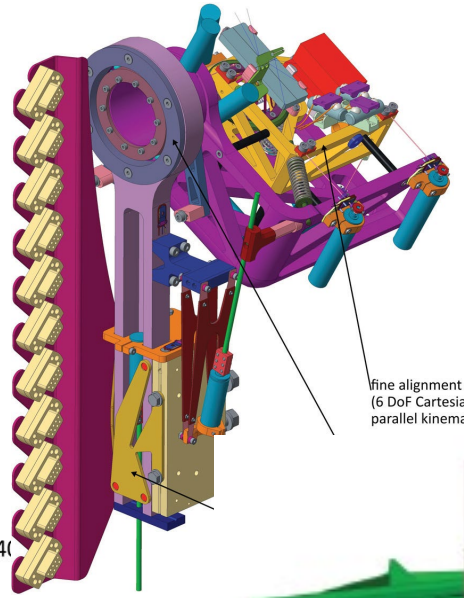
- Separate positioning stages mounted to the optical bench for all optical elements
- Demands:
  - Providing **a fast long-range travel** – in some cases of up to 1000 mm
  - Allowing a precise alignment with a **resolution in the range of single nanometre and tens of nanoradians**

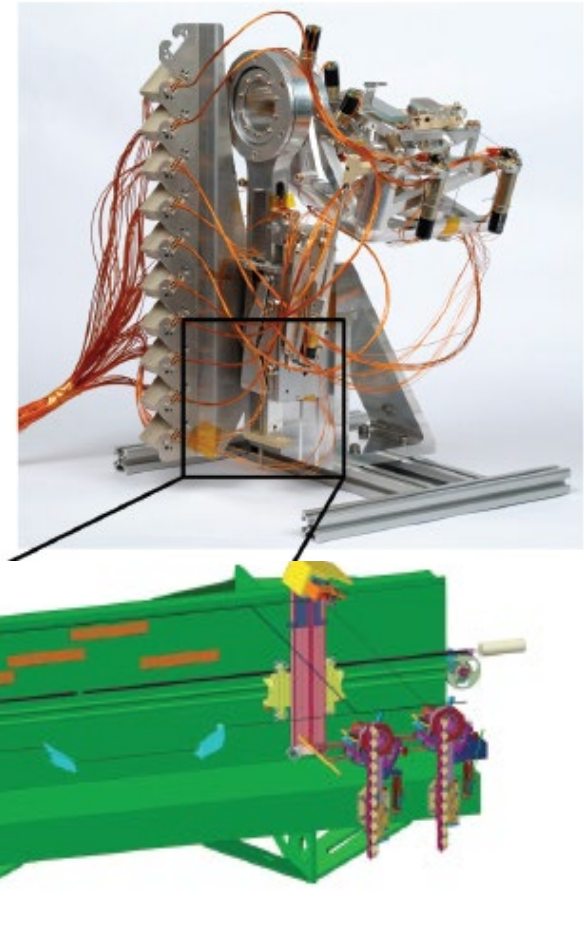


Conceptual view of the SDL indicating the mechanical concept. a) beam splitters; b) upper branch crystals; c) channel cuts; d) beam merger.

Positioning stage for the beam splitter.

- Serial combination of coarse motion axes with a fine alignment stage
- The fine alignment stage is implemented as a 6 DoF Cartesian parallel kinematics.





ISBN 978-3-95450-188-5 53 Proceedings of MEDSI2016, Barcelona, Spain

HED Instrument

https://www.xfel.eu/facility/instruments/hed/index_eng.html

- Combining hard X-ray FEL radiation and the capability to apply extreme conditions of pressure, temperature or electric field using the FEL, high energy optical lasers, or pulsed magnets.

https://www.xfel.eu/virtualtour/#node42

- Diamond Anvil Cells (available)
  dynamic DAC; pulsed laser heated DAC; double-stage DAC
- Powerful optical lasers (2020-2021)
  100 J 15 ns 10 Hz; 400 TW 30 fs 10 Hz
- XFEL split&delay line (2021) x-ray pump-probe, 0-20 ps delay
- 60 T pulsed magnetic field coil (2021)
  cryogenic sample environment, superconductivity

The goal will be to achieve pressures of 1 TPa and temperatures up to 10 000 K using 5 ns, frequency-doubled 50 J pulses from the DiPOLE100X laser focused to 100 µm

Additional laser

	Abbreviation	Repetition [Hz]	Wavelength [nm]	Pulse energy	Pulse duration	Max. power or B field	Remarks
Pump–probe laser	PP-OL	4.5 M	~ 800	0.2 mJ / 4.5 MHz 5 mJ / 200 kHz	15–00 fs	10–250 GW	NOPA
		200 k	~ 1030	100 mJ	0.8 ps or 0.5 ns	~ 100 GW	Yb amplifier
High-energy laser	HE-OL	1–10	1057 or 1064	~ 150 J/ω ~ 100 J/2ω	2–20 ns	~ 75 GW	Nd-glass or Nd-YAG
		< 1	528 or 532	> kJ	2–20 ns	> 500 GW	Beyond 2016
Ultrahigh-intensity laser	UHI-OL	10	~ 800	3–5 J	~ 30 fs	~ 100 TW	Ti-sapphire
		~ 1		10–30 J	~ 30 fs	~ PW	Beyond 2016
High-field pulsed magnet	HFM	0.1 – ~ 0.01	—	~ 30 kJ	> 100 µs	> 30 T	—
		< 0.01	—	> MJ	—	TBD	Beyond 2016

FXE Instrument

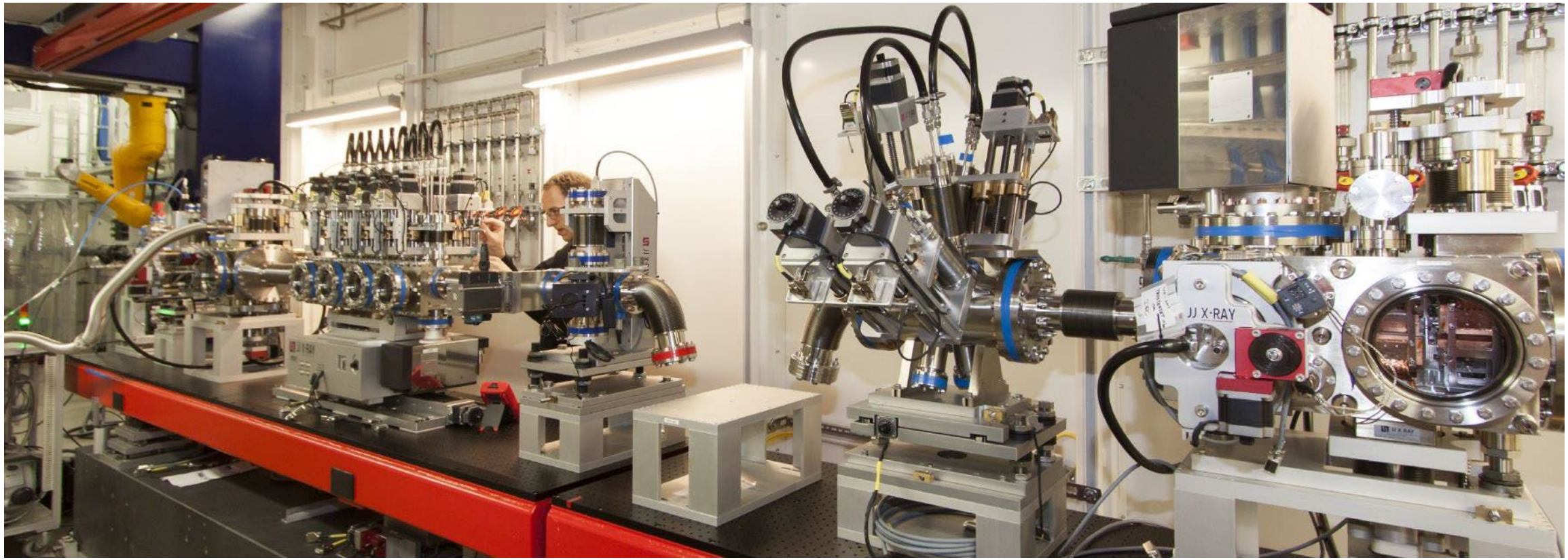
https://www.xfel.eu/facility/instruments/fxe/index_eng.html

- Enables ultrafast pump–probe experiments on ultrafast timescales—below 100 femtoseconds

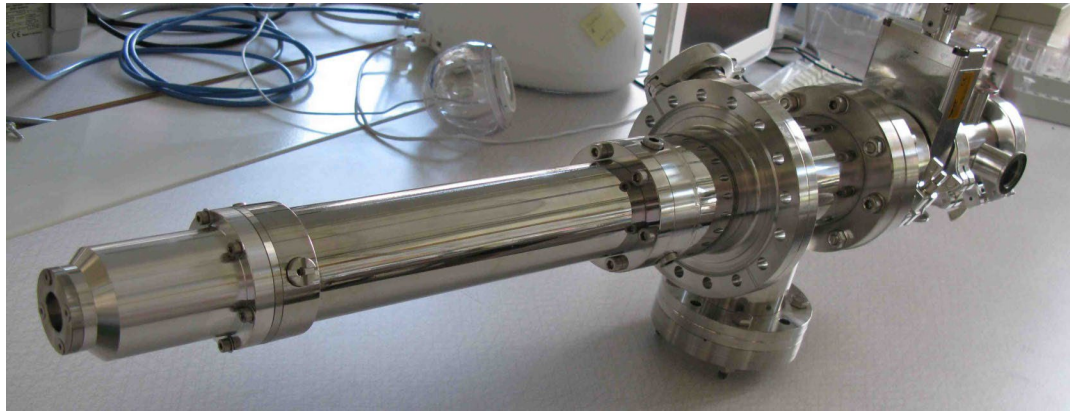
- Supported techniques:
  - X-ray diffraction (XRD)
  - X-ray diffuse scattering (XDS), or wide-angle X-ray scattering (WAXS)
  - X-ray emission spectroscopies (XES): non-resonant, or resonant inelastic X-ray scattering (RIXS)
  - X-ray absorption spectroscopies: X-ray absorption near-edge structure (XANES), or extended X-ray absorption fine structure (EXAFS)

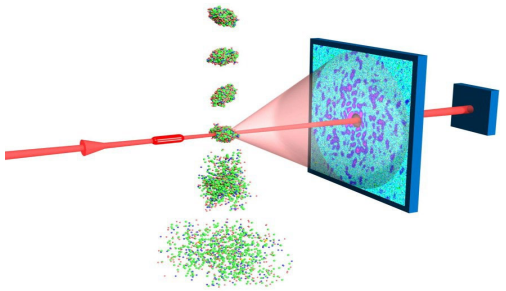
Parameter	Current value
Photon energy range	5–20 keV
Polarization	Linear (horizontal), circular (future option)
X-ray pulse duration	50 fs FWHM
Beam size	8–200 µm adjustable (via several Be lenses)
Special optics	1 primary 4-bounce Si(111) mono 2 secondary (von Hamos, Johann) spectrometers
Optical laser wavelengths	Pump–probe (0.1–1 mJ) 800 nm (15–100 fs) Pump–probe (200 µJ) 800 nm (50 fs, 15fs possible), harmonics, TOPAS adjustable UV-vis-NIR Pump–probe (>20 mJ) 1030 nm (850 fs) Pump–probe (>50 µJ) 1 mm (=0.3 THz) generated via optical rectification
X-ray detectors	APD (0D, full rep. rate with MHz DAQ) Gotthard (1D, 1280 px, 50 µm pixel pitch, 0.9 MHz) Jungfrau (2D, 1024 x 1024 px, 75 x 75 µm pixel size, 10Hz) LPD (2D, 1 Mpx, $(500\ \mu m)^2$ pixel size, 512 frames at 4.5 MHz, 3-fold dynamic gain covering 1 (SP at 12keV) to $1x10^4$ per pixel)

Assembling the scientific instruments



In-kind contribution SE01 for WP79 Sample Injection Technology





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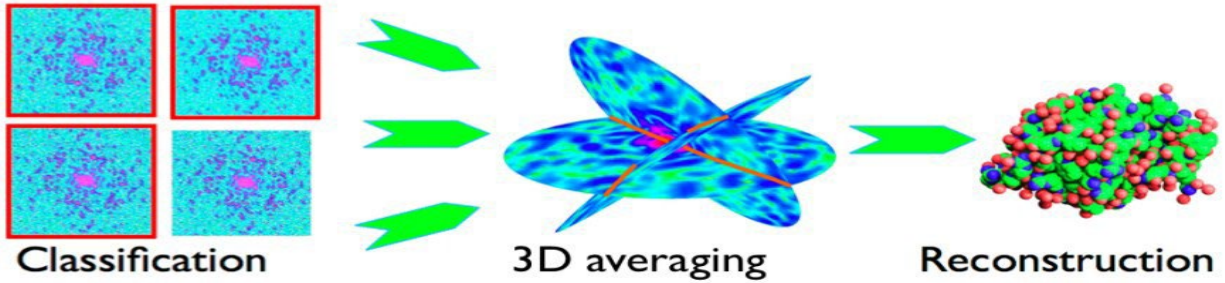
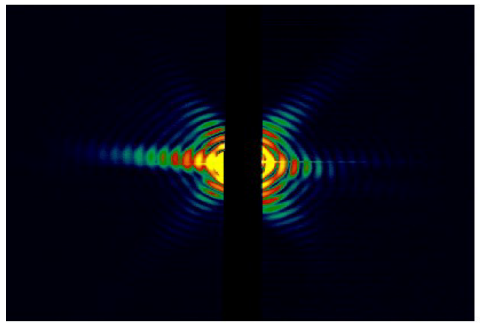
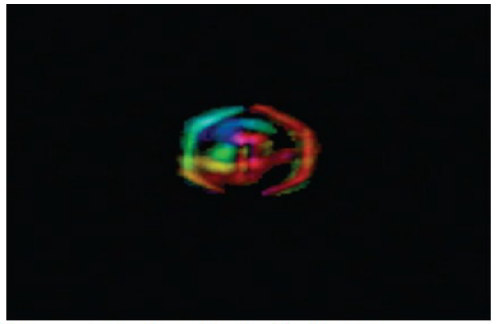


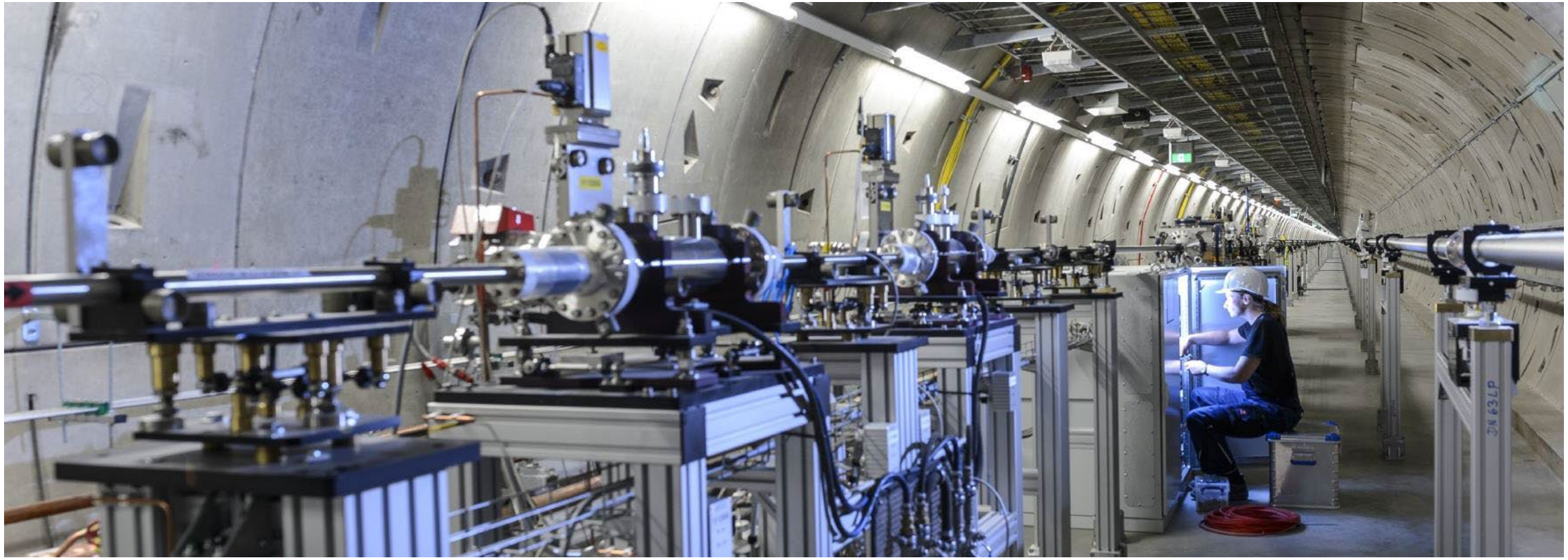
Operation:
1. Many single particle images
2. Classify for orientation
3. Average each class
4. Combine to 3D image
5. Reconstruct



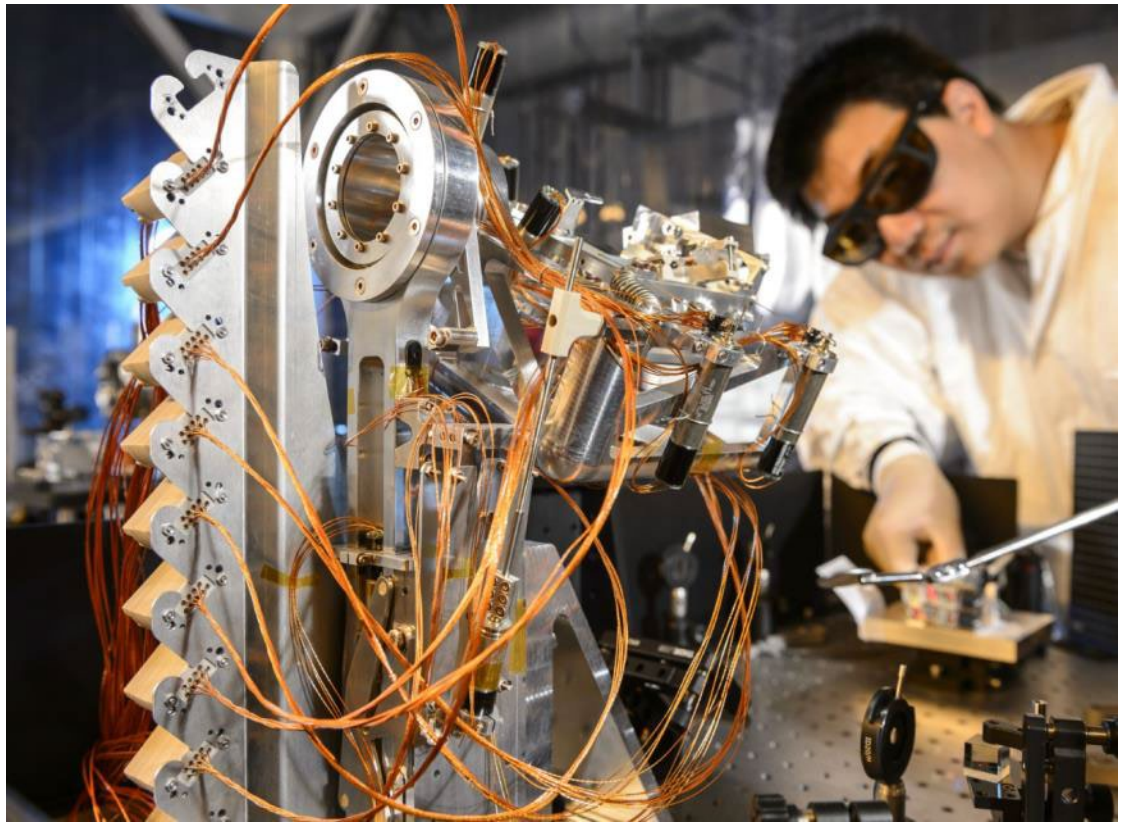


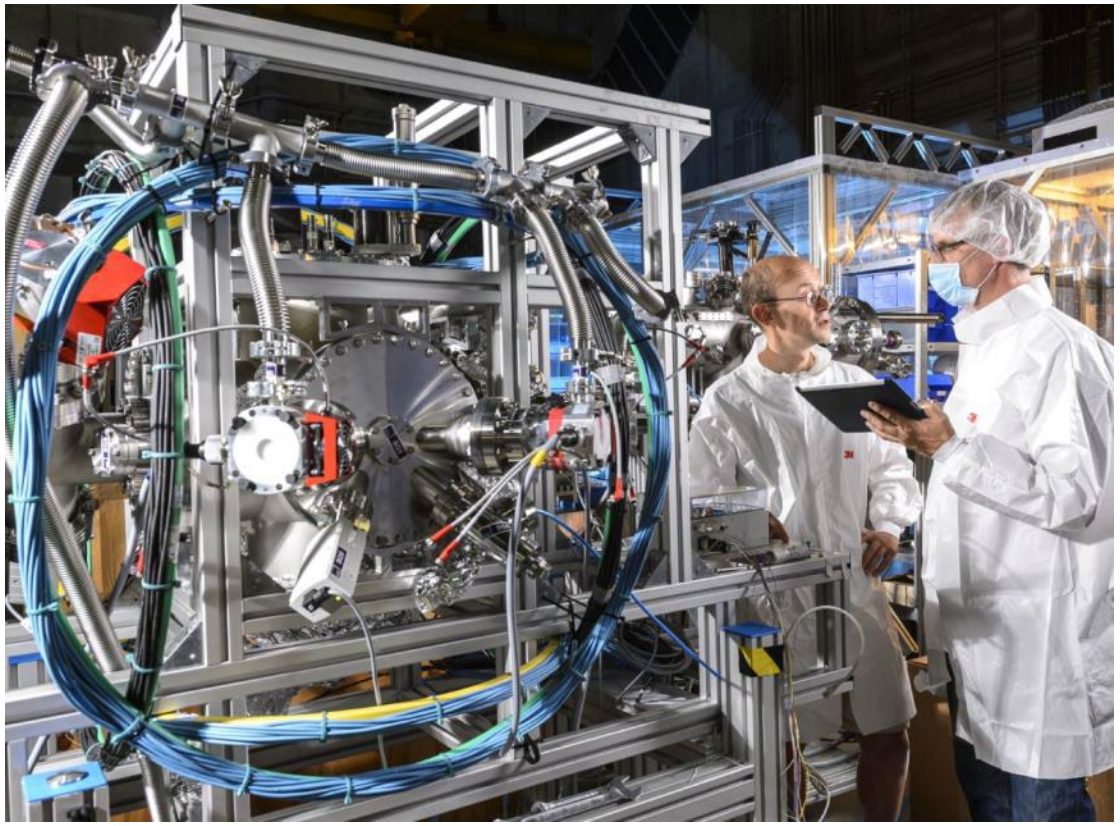
Reconstruction by Anton Barty
Relaxed Averaged Alternating Reflection

Photon beamlines



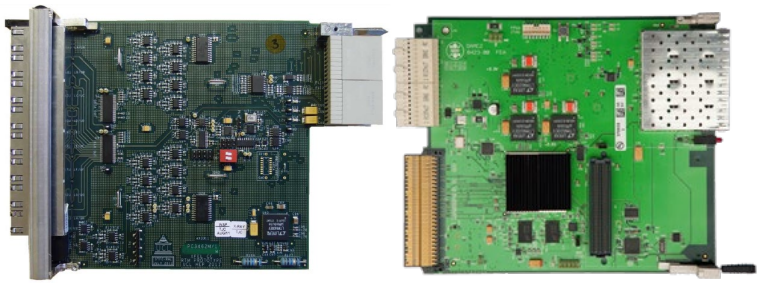
Assembling the scientific instruments





MicroTCA Standard

MicroTCA 9U Crate



Advance Mezzanine Card (AMC) with a Rear Transition Module (RTM)

MicroTCA® is a modular, **open standard g**eared towards a more compact, less expensive systems, without cutting back on reliability or data throughput

- Created and maintained by the PCI Industrial Computer Manufacturers Group https://www.picmg.org/openstandards/microtca/
  - **Target Applications:** Industrial control, Automation, Medical, Communication, High-Energy & Nuclear Physics among others
  - Institutes/Companies involve in the definition include DESY, SLAC, Intel, Ericsson, AMD, Pentair, etc.…
- Located at the DESY campus, the **MicroTCA Technology Lab** offers a wide range of related services (hardware, training, consulting…)
  - https://techlab.desy.de/

General MicroTCA Infrastructure

MicroTCA Crates

Large 12 slot 9U and small 6 slot 2U (including MCH, Power Supply and CPU)

~60 Crates

X2Timer

XFEL Timing System module for synchronization (clocks and triggers) and pulse parameters from NAT

~100 Cards

DAMC2

Required for Clock & Control system for fast 2D detectors, VETO System, Machine Protection System and photon beam loss monitors from DESY

SIS8300

Fast 125MSPS ADC with 10 channels and 16bit resolution for diagnostics and detectors from Struck Innovative Systeme

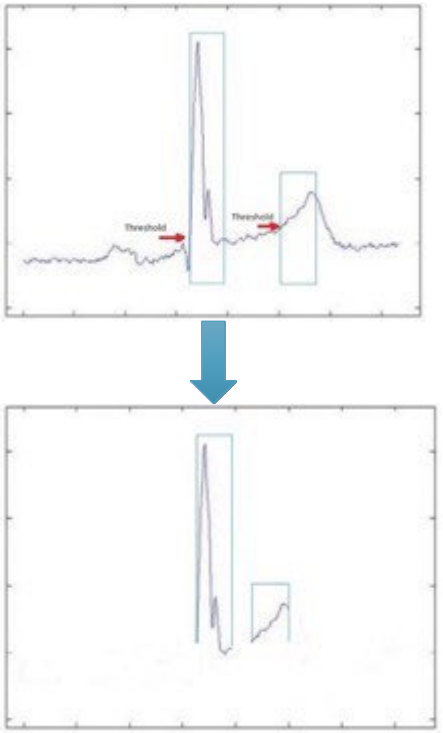
~300 Channels

ADQ412/ADQ14/ADQ7

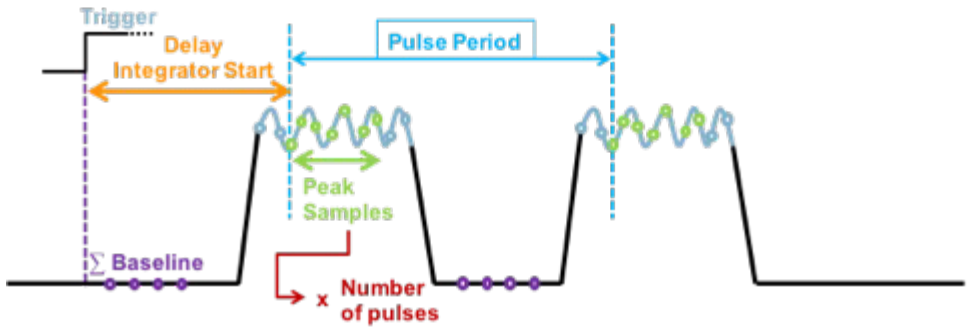
High-speed digitizers from 1.8GSPS to 10GSPS with 12 to 14 bit resolution from Teledyne SP Devices

~100 Channels

FPGA processing algorithms and interfacing standards – Signal processing

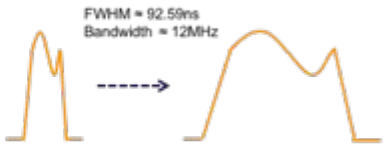


Zero Suppression

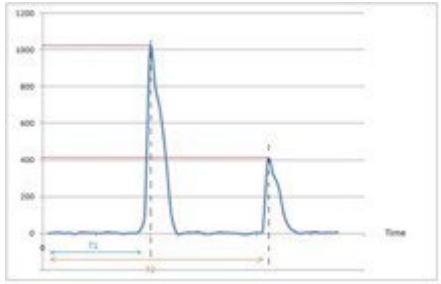


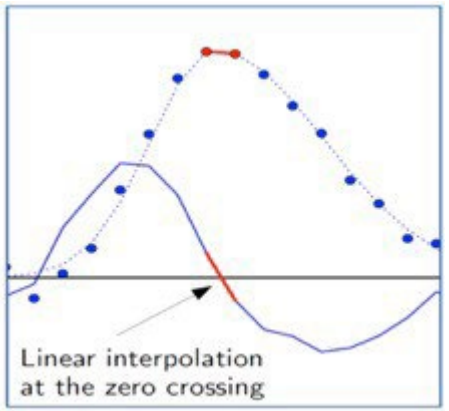
Pulse Stretcher RTM

- 10 SMA Connectors
  - 2 Direct channels
  - 8 Stretched channels
- Configurable DC Output
  - Open/+1.2V/-1.2V



Pulse Integration

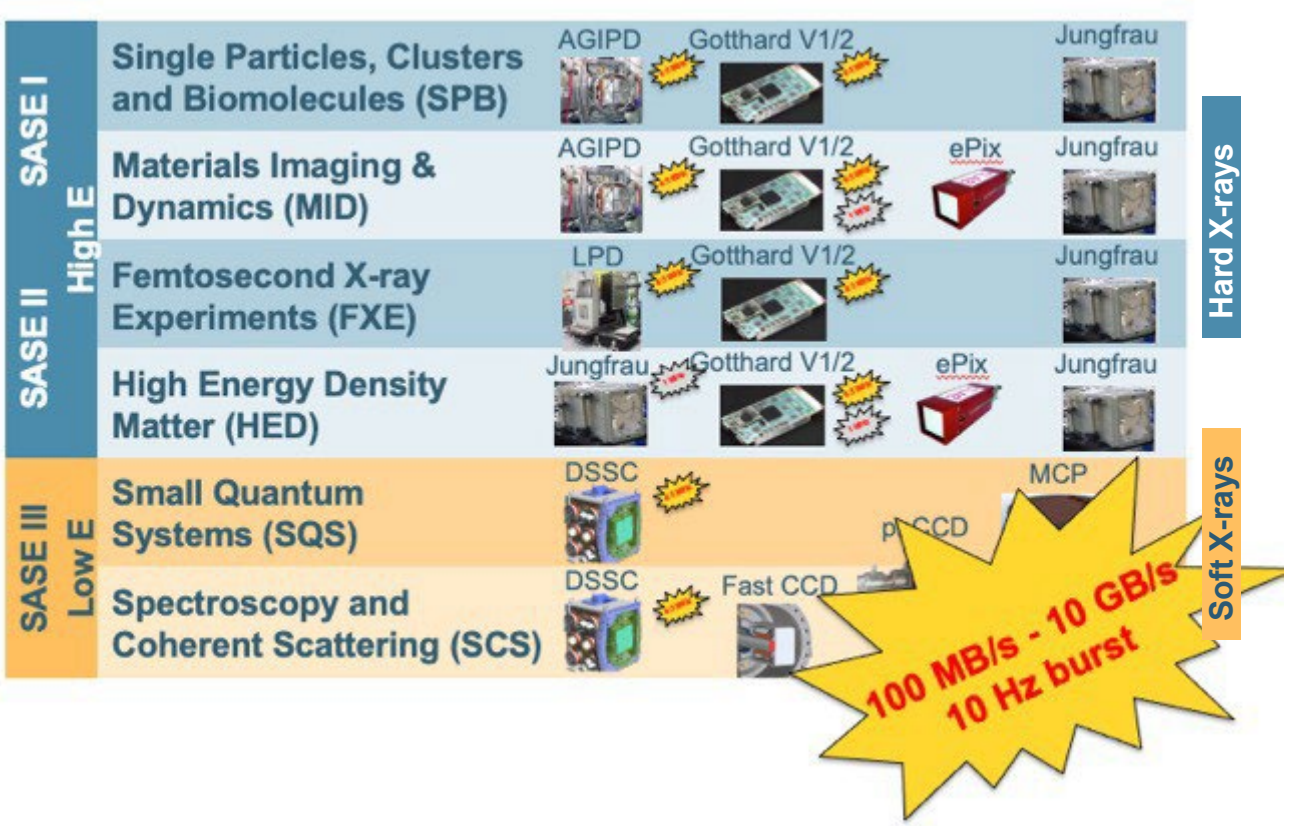




Peak Time Detection

Handling Data and Complexity

X-Ray Detectors at EU.XFEL Instruments



Custom FPGA-based Data Producers at EU.XFEL

Technology of interest - 2022

- **UHV vacuum chambers in Aluminum alloy**, with bi-metallic flanges, without use of welding, in the direction of the beam.
- **Hard X-ray Wavefront Sensor (HXWFS)** device based on the Hartmann sensor
- **Interferometer solution** capable of measuring the longitudinal position of a carriage (about 0,5-1,5 cm width and 3mm height) over a more than 8m-long straight line, with a required accuracy of the longitudinal position measurement is 1um
- **Polycrystalline CVD diamonds** (chemical vapour deposition)
- **High resolution Raman confocal microscopy**
- Mechanical design and delivery of **optical holding systems** and its **large UHV chamber** with manual and remote micrometric control adjustment.
- **UHV compatible linear translation stages** moving in the vertical/horizontal axis by a travel range of more than 2 cm till 7 cm, with a spatial movement resolution less than 0,1 um
- **X-ray coatings of X-ray coatings** in B4C, metals (for instance Platinum, Gold, Chromium) for mirrors and gratings (made typically by silicon)
- **X-ray mirrors** large about 1 m (or even more) with a substrate in Silicon single crystal <100>, Meridional radius >200 Km, surface height error <20 nm peak to valley.
- **Semi-customized XUV spectrometer** with spectral range between 5 –200 nm, spectral resolution λ / Δλ 300-1200 and spatial resolution less than 15 μm with 3 Modes of operation - Beam inspection, angularly dispersed XUV spectroscopy, focusing along non-dispersion axis.
- **Laser engraving machine**, table top device with a writing area that can contain a square with a size more than 120mm. The machine must be able to write on rods/tubing down to 5mm diameter.
- **Cold finger** with an integrated probe holder with two grooves for a temperature sensor and a hall probe.

Technology of interest - 2023

- **(piezo) actuators with controllers** that are encoded, UHV compatible, with low magnetic permeability (< 1.01μr), few Newton force and with nanometric resolution
- 50-100 pieces of **compound refractive lenses made of pure beryllium**
- **High time resolution, 4 channel real-time oscilloscope** with more than 25 GHz bandwidth, more than 70 GS/s sample rate and more than 13 Gb/s serial trigger Sensitivity is requested better than 3 mV-1 V/div.
- **Linear stage** that moves in horizontal direction a static load more than 2500N
- **Pulse tube with compressor** separated from the installation flange for low vibration application, UHV compatible, with low magnetic permeability (about 1.05μr) and able to extract more than 20W at less than 100K.

Requests of 2024

- Alignment Table:
  - Dimensions: Length/Width between 800-1200 mm, height between 500-950 mm.
  - Translation: 80-100 mm along two main axes, resolution of 1 micron.
  - Rotation: 8-12 degrees, precision <0.02 degrees.

- Cryocooler System:Temperature
  - Stability: ±0.02K at the sample.
  - Cooling Power: 1st Stage >15W, 2nd Stage >1.5W at 4K.T
  - Temperature Range: 4K - 325K.

- Gas Mixers:
  - Mixed gases: Argon and Neon.Input pressure: ~7-9 bar;
  - Mixed pressure: ~4-6 bar. Adjustable mixing ratio: 0-100%,
  - Withdrawal rate: <<1 to ~50 Nl/min.

- LEED System:
  - Low current operation down to picoampere with MCP or equivalent detector. Integral lock-in amplifier for LEED and Auger measurements.

- High-Frequency Piezo Disks:
  - Diameter: 5-12 mm, Thickness: 1-2 mm. Frequency: 1-5 MHz, material suitable for wire soldering.
  - X-Ray Spectrometer:Designed for nonlinear soft X-ray spectroscopy.Grating chamber with up to three gratings, and motorised rotation with microradian accuracy.

Campus constructions

Plans for the other major part of the European XFEL:

- An accommodation service, the facility's 59-room Guest House - were finalized and it is in operation.
- …and a 940 m^2 building for tuning and measuring the facility's X-ray generating undulators was just finalized.
- A visitor centre, including school laboratories and an auditorium, was approved by the European XFEL Council in November 2018. It will also receive significant funding from Schleswig-Holstein.
- A building housing infrastructure for the HED instrument as well as offices for staff members and users has been finalized.

Conclusion

- European XFEL is an international big science large facility
- The construction is completed but there are a lot of opportunities to collaborate on new devices

For any question please write to **ilo@xfel.eu**