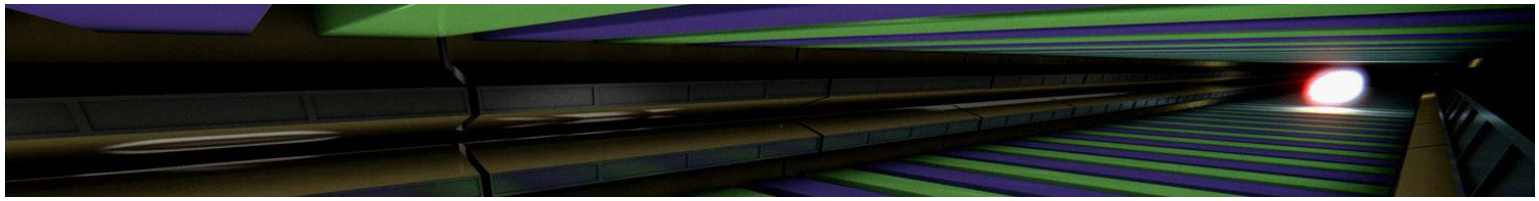


XFEL - Project status

Martin Sachwitz

on behalf of the XFEL Collaboration

European X-Ray Free-Electron Laser Facility

22761 Hamburg, Germany

European XFEL

History – TESLA Project 2001

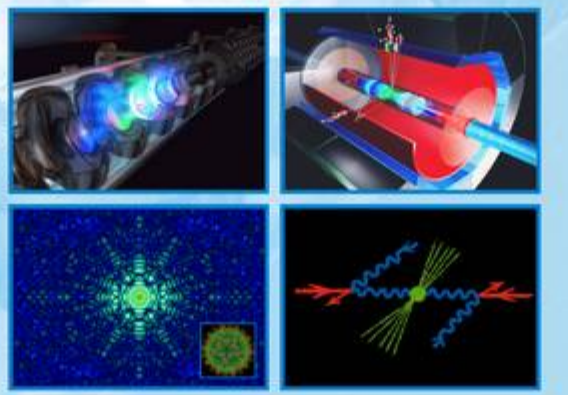
TESLA

TESLA

The Superconducting Electron-Positron Linear Collider

with an Integrated X-Ray Laser Laboratory

Technical Design Report



European XFEL

TESLA Project 2001

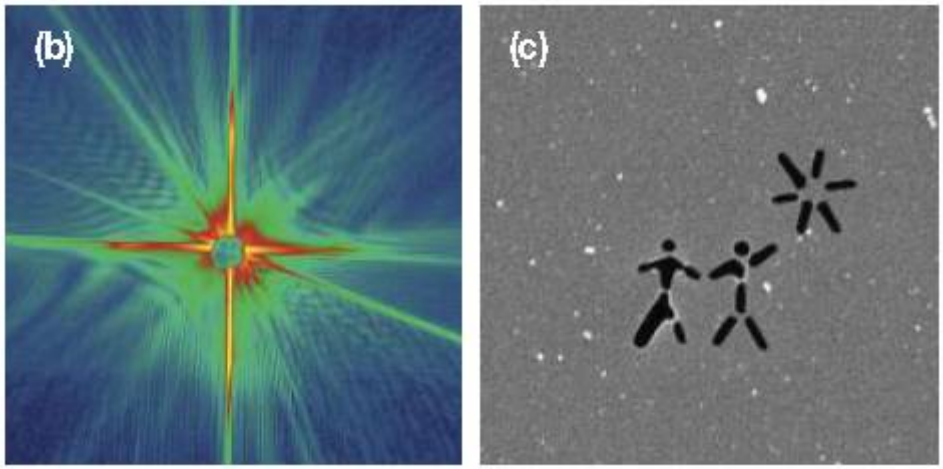
XFEL became European project

The Tesla Project was NOT approved by the German government

European XFEL

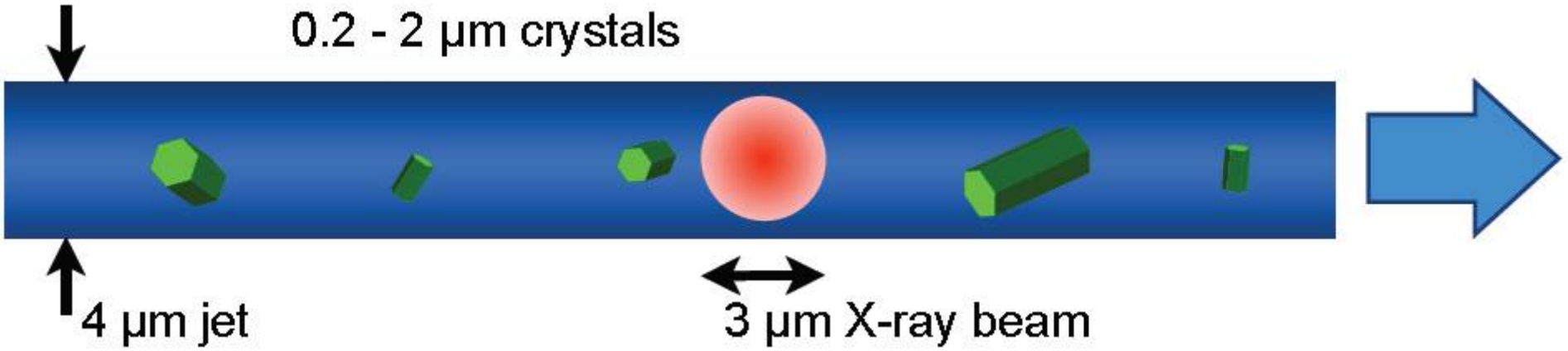
Purpose of the European XFEL - Microscope

- It is simply a Microscope

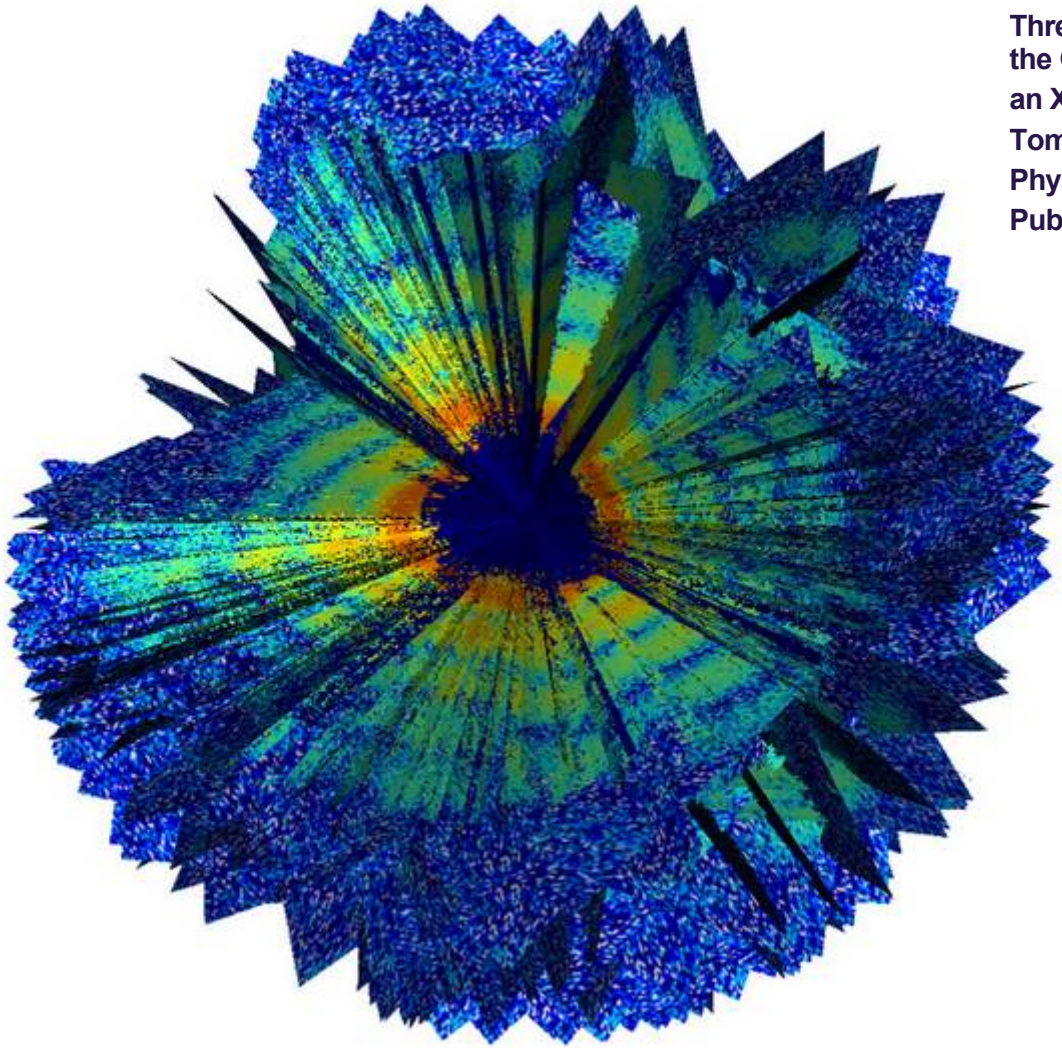


Purpose of the European XFEL – 3D Microscope

- It is simply a Microscope
- Even better: 3D Microscope



Purpose of the European XFEL – 3D Microscope

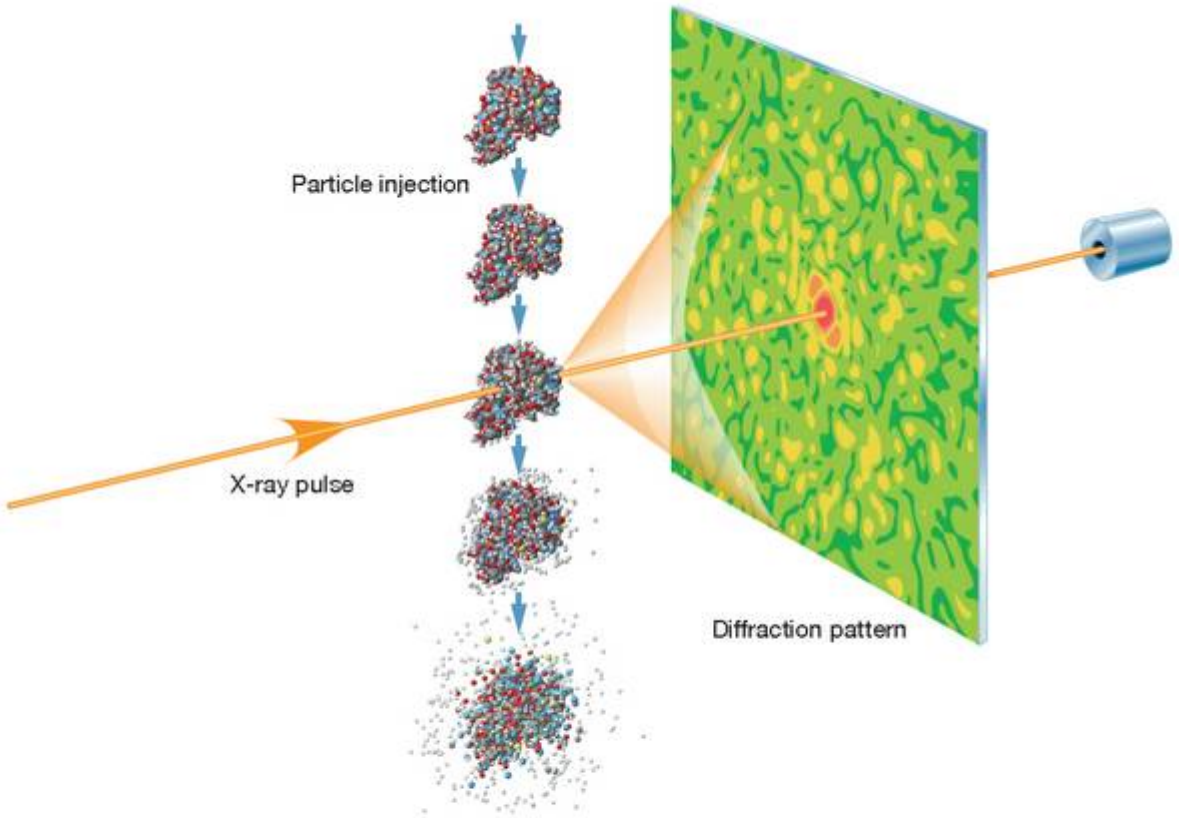


Three-Dimensional Reconstruction of the Giant Mimivirus Particle with an X-Ray Free-Electron Laser
Tomas Ekeberg *et al.*
Phys. Rev. Lett. 114, 098102
Published 2 March 2015

Purpose of the European XFEL - High speed camera

- It is simply a Microscope
- Even better: 3D Microscope
- Best: High speed camera

Purpose of the European XFEL - High speed camera

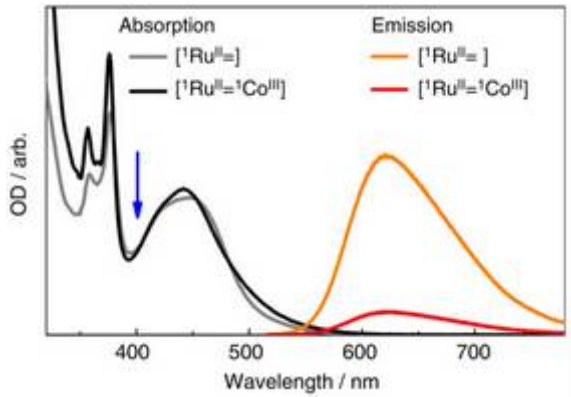


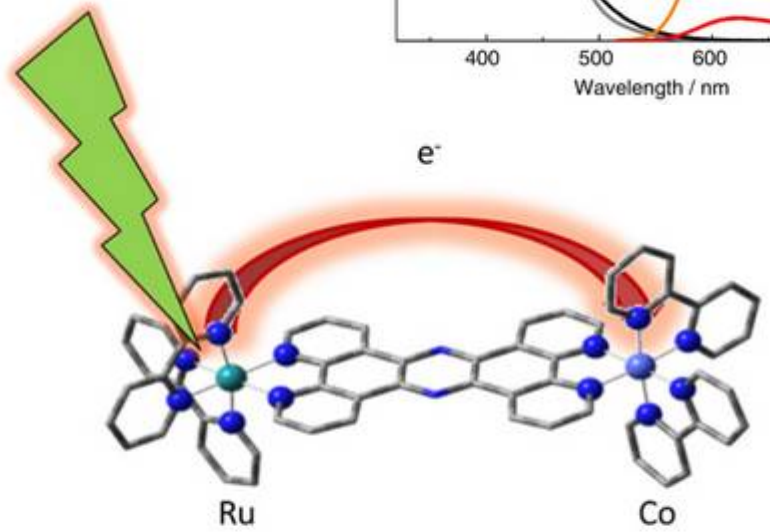
Imaging of “big” and “small” non-crystalline samples

Purpose of the European XFEL - High speed camera

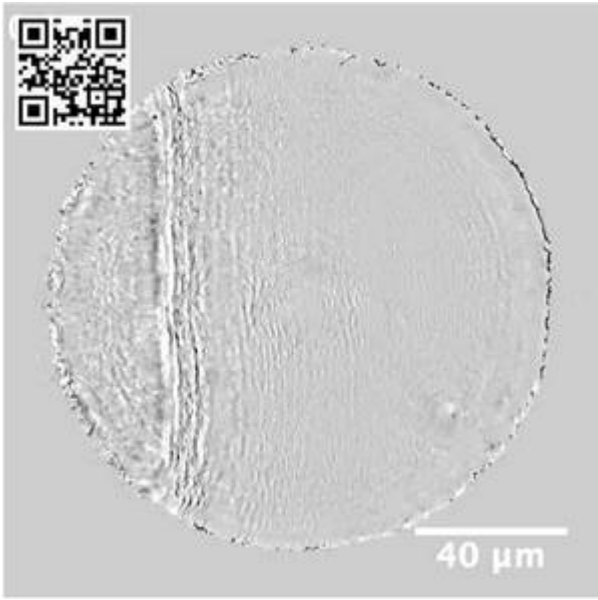
- C. Bressler et al

Femtosecond X-Ray Experiments (FXE) instrument group from European XFEL





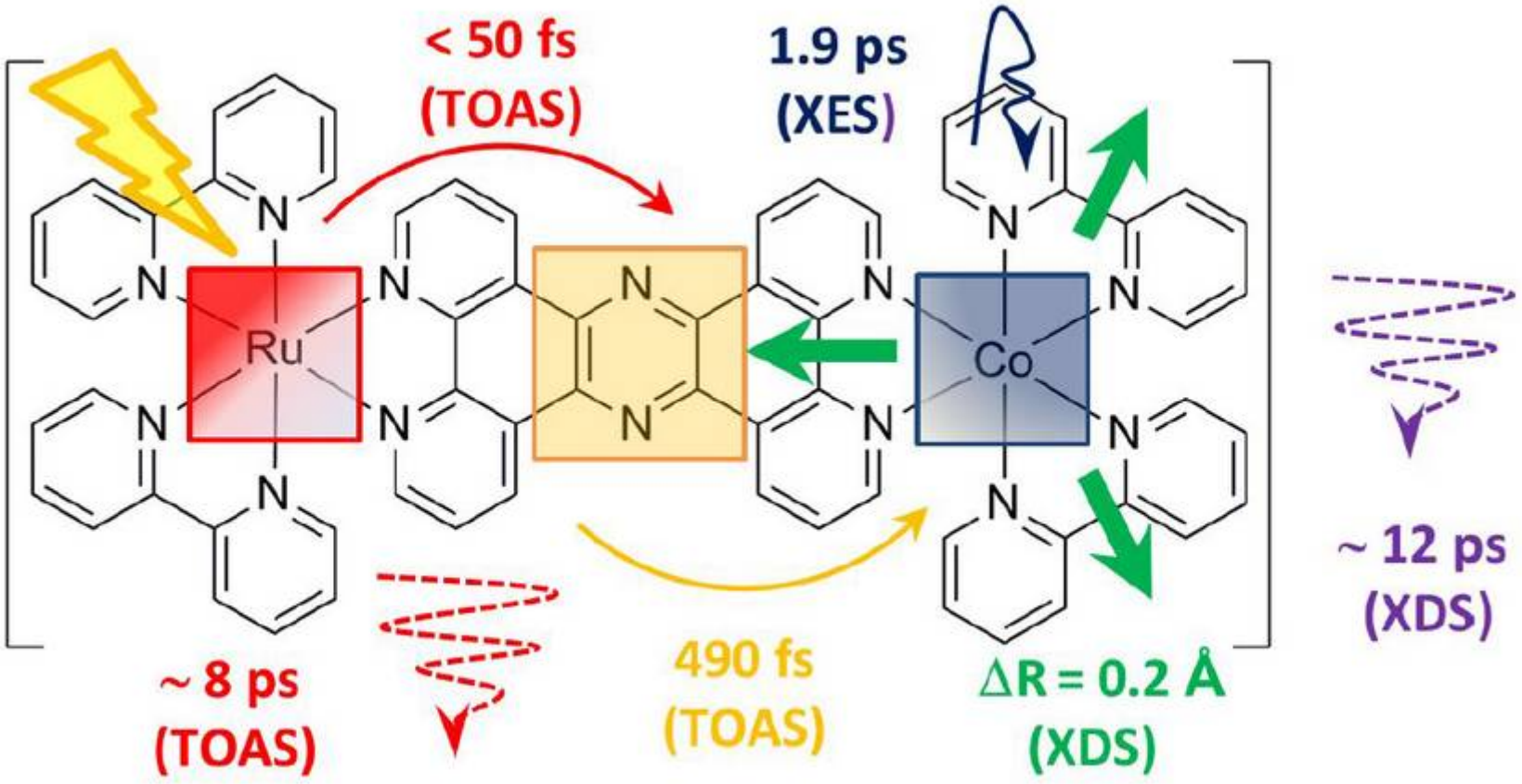
The scientists energized the ruthenium end of the molecule (left) with an optical laser pulse and, using X-ray FEL pulses, could see changes in the molecule as the electron moved to the cobalt atom (right).
Technical University of Denmark and Lund University



Imaging Shock Waves in Diamond with Both High Temporal and Spatial Resolution at an XFEL; Andreas Schropp et al; *Scientific Reports*, 2015; DOI: 10.1038/srep11089

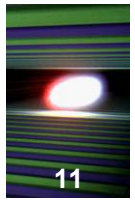
Purpose of the European XFEL - High speed camera

- The full reaction cycle revealed with complementary tools



S. Canton, *et al.*, accepted Nat. Commun. 2015

What do you need to build such a unique camera?



- high resolution (0.05 nm laser wavelength)

Project	LCLS, USA	SACLA, Japan	European XFEL	SwissFEL, Switzerland	PAL XFEL, Korea
Wavelength range (nm)	0.12–4.4	0.06–0.3	0.05–4.7	0.1–7	0.06–10

- high speed (27 000 flashes/sec, fsec duration

Pulses/second	120	60	27000	100	60
Photons/pulse	10^{12}–10^{13}	2×10^{11}	up to 10^{14}	~ 3.6×10^{10}	10^{11}–10^{13}

- brilliance (5 10^{33} photons/sec/mm^2 mrad^2 /0.1%bandwith)

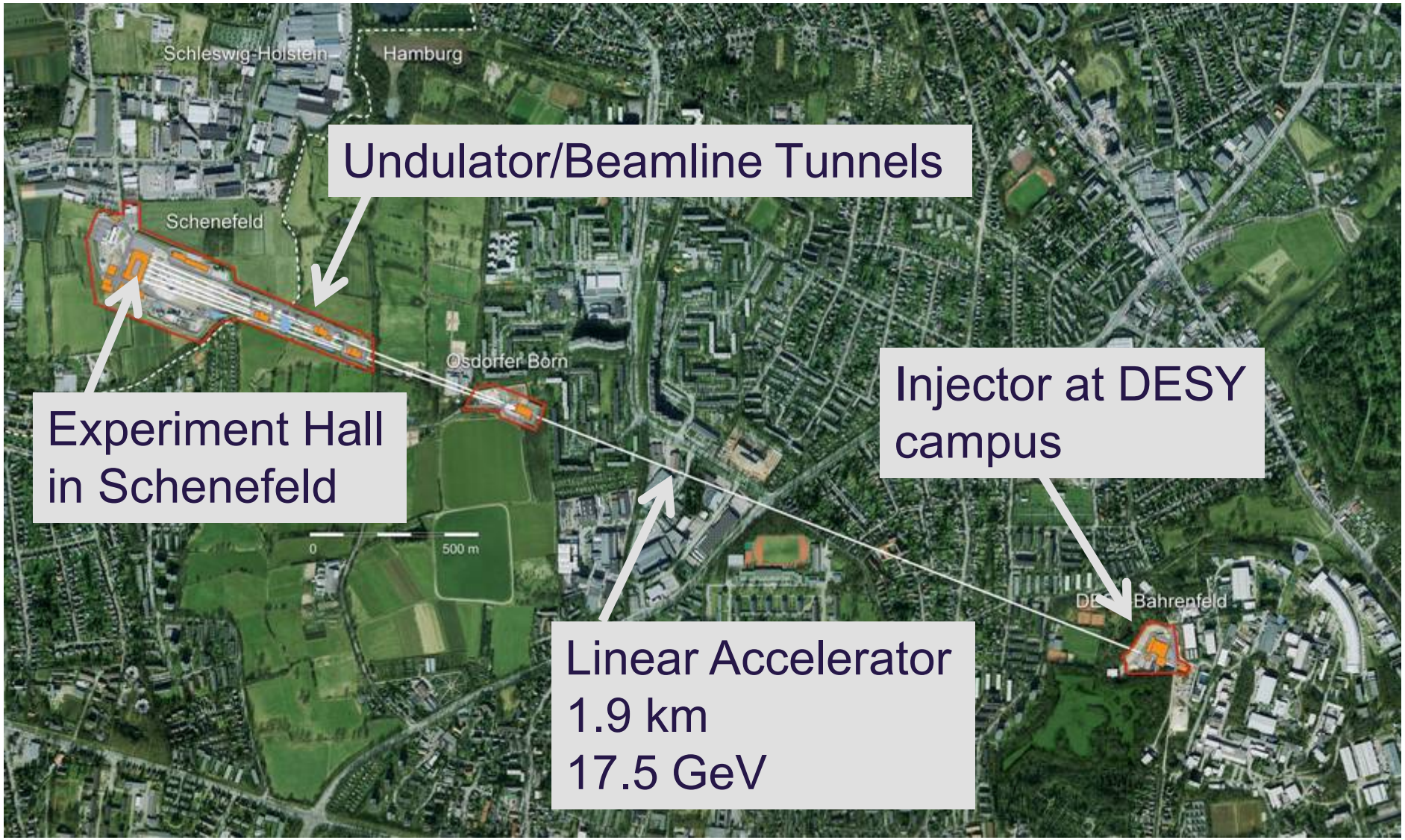
Peak brilliance	1.5×10^{33}	1×10^{33}	5×10^{33}	7×10^{32}	1.3×10^{33}

What do you need to build an XFEL

- Good, experienced friends not only from Europe but from all over the world
- Right area (earthquake, tsunami….) with high level infrastructure
- A long Tunnel with an
  - Electron-Gun,
  - Electron Accelerator part,
  - Electron to Light - Machine (called Undulator),
  - Experimental setups

European XFEL

European XFEL layout

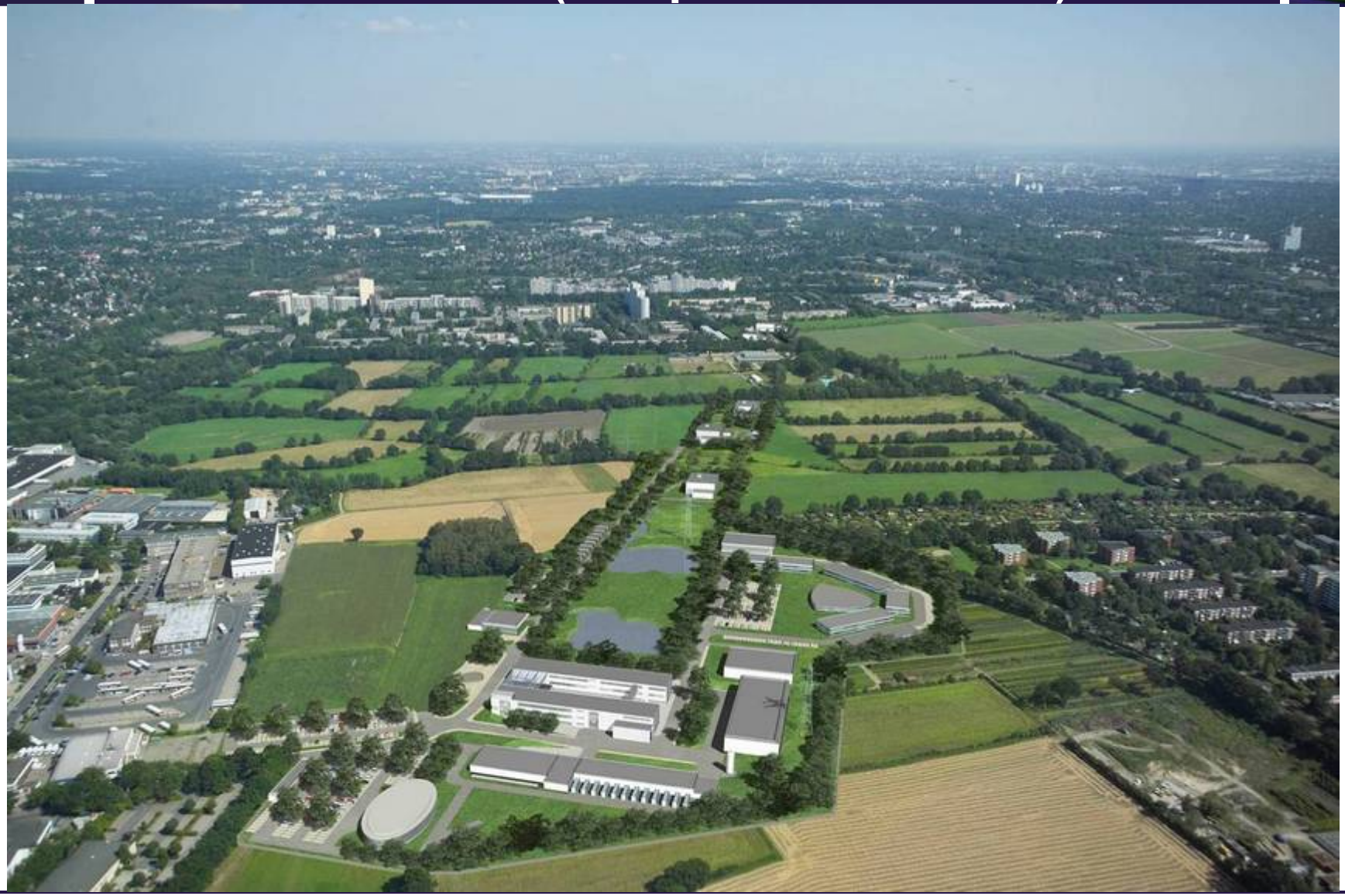


European XFEL

XFEL site in Hamburg/Schenefeld

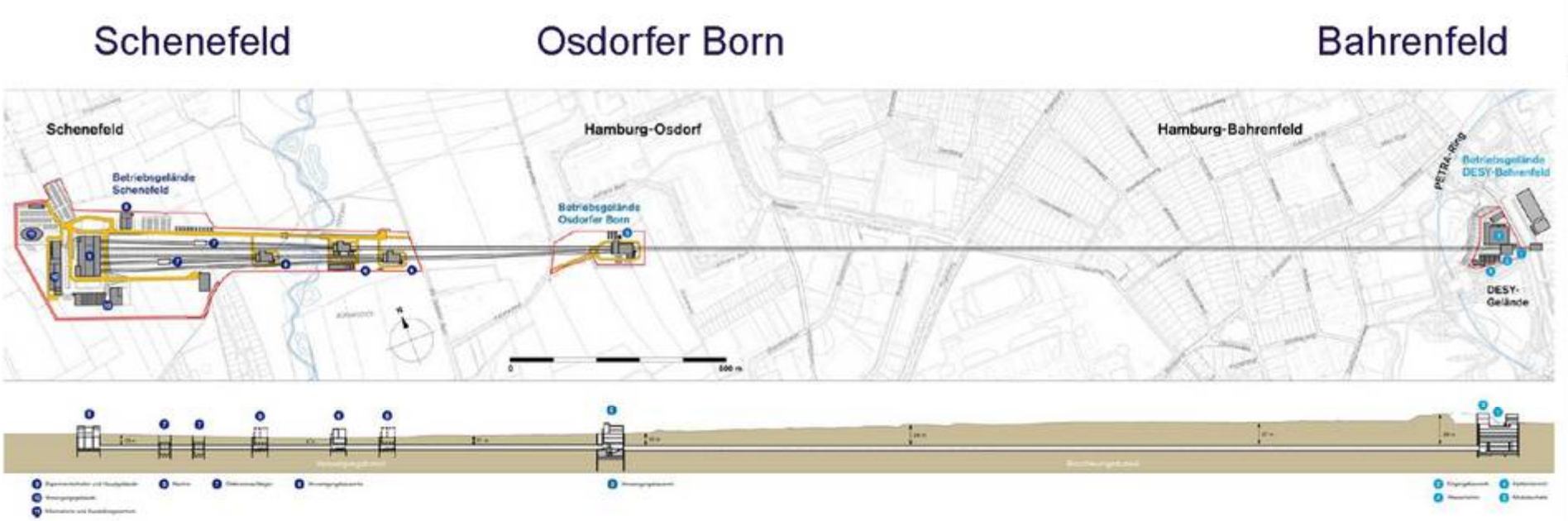
European XFEL

After construction (computer simulation)



European XFEL

XFEL Facility Underground



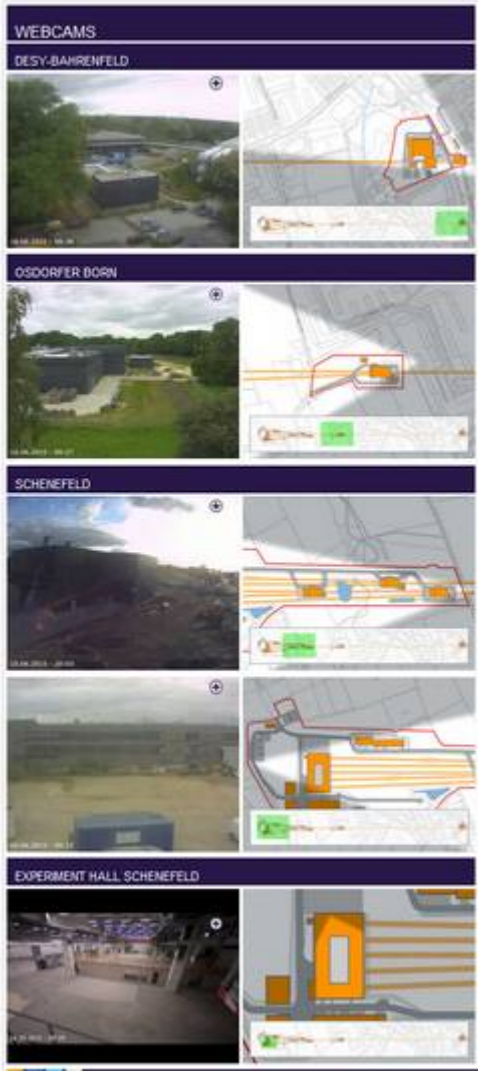
- Three construction sites
- 5.8 km tunnels
- 12,000 m^2 surface are buildings
- 150,000 m^3 of underground building volume

	LCLS	SACLA	European XFEL
Abbreviation for	Linac Coherent Light Source	SPring-8 Angstrom Compact Free Electron Laser	European X-Ray Free-Electron Laser
Location	California, USA	Japan	Germany
Start of commissioning	2009	2011	2016
Accelerator technology	normal conducting	normal conducting	superconducting
Number of light flashes per second	120	60	27 000
Minimum wavelength of the laser light	0.15 nanometres	0.08 nanometres	0.05 nanometres
Maximum electron energy	14.3 billion electron volts (14.3 GeV)	6-8 billion electron volts (6-8 GeV)	17.5 billion electron volts (17.5 GeV)
Length of the facility	3 Kilometer	750 Meter	3.4 Kilometer
Number of undulators (magnet structures for light generation)	1	3	3, upgradeable to 5
Number of experiment stations	3-5	4	6, upgradeable to 10
Peak brilliance [photons / s / mm^2 / mrad^2 / 0.1% bandwidth]	$2 \cdot 10^{33}$	$1 \cdot 10^{33}$	$5 \cdot 10^{33}$
Average brilliance [photons / s / mm^2 / mrad^2 / 0.1% bandwidth]	$2.4 \cdot 10^{22}$	$1.5 \cdot 10^{23}$	$1.6 \cdot 10^{25}$

- Superconduction allows the creation of an electron beam of especially high quality composed of many electron bunches aligned one behind the other.
- This enables the European XFEL to generate many more light flashes per second than the other two facilities.
- The number of usable light flashes is increased as well.
- Certain experiments will thus only be possible at the European XFEL, and others can be carried out much faster.
- The higher number of electron bunches also allows more experiment stations to be operated simultaneously.

European XFEL

http://www.xfel.eu/project/webcams



- **European XFEL GmbH**

(GmbH = a non-profit limited liability company under German law)

- 11 countries are participating in the project

Denmark, France, Germany, Hungary, Italy,

Poland, Russia, Slovakia, Spain, Sweden, and Switzerland

- Construction costs of the facility: 1.15 billion Euro
- Germany covers 58% of these costs.
  Russia bears 27% and the other international partners between 1% and 3%.
- Construction started in early 2009
- Commissioning is planned for 2016

European XFEL

Shareholder of the European XFEL GmbH

Present (bold) or likely future shareholder of the European XFEL GmbH	Country
DASTI (Danish Agency for Science, Technology and Innovation)	**Denmark**
CEA (Commissariat à l'énergie atomique et aux énergies alternatives), CNRS (Centre national de la recherche scientifique)	**France**
DESY (Deutsches Elektronen-Synchrotron)	**Germany**
NIH (National Innovation Office)	**Hungary**
Republic of Italy, represented by the Ministero dell'Istruzione, dell'Università e della Ricerca	Italy
NCBJ (National Centre for Nuclear Research)	**Poland**
OJSC RUSNANO (Open Joint Stock Company RUSNANO)	**Russia**
Slovak Republic, represented by the Ministry of Education	**Slovakia**
Kingdom of Spain, represented by the Ministerio de Economía y Competitividad	Spain
VR (Vetenskapsrådet, Swedish Research Council)	**Sweden**
Swiss Confederation, represented by Staatssekretariat für Bildung und Forschung	**Switzerland**

Russian Contribution via Open Joint Stock Company RUSNANO

- Press release RUSNANO 15th March 2015:

- Строительство Европейского рентгеновского лазера на свободных электронах (European XFEL) — международный научный проект с участием 11 стран, реализуемый в Гамбурге (Германия).

- РОСНАНО представляет в данном проекте интересы Российской Федерации и осуществляет его финансирование по поручению Правительства.

- Объем инвестиций РОСНАНО в XFEL составит €306,4 млн (в ценах 2005 года)

.

- На настоящий момент доля ОАО «РОСНАНО» в XFEL составляет 26,24%.

European XFEL

Large Russian Contribution

WP1 RF System	BINP Novosibirsk
WP10 Module Test Facility	IHEP Protvino
WP12 Warm Magnets	NIIEFA St.Petersburg
WM13 Cryogenics	IHEP Protvino
WP14 Injector	JINR Dubna
WP17 Standard Beam Diagnostics	IHEP Protvino
WP18 Special beam Diagnostics	INR Troitsk
WP19 Warm Vacuum	BINP Novosibirsk
WP20 Beam Dump	IHEP Protvino
WP28 Control Systems	IHEP Protvino
WP33 Tunnel Installation	IHEP Protvino
WP34 Utilities	BINP Novosibirsk

WP21 Undulators
BINP Novosibirsk

WP24 Photon Diagnostics
PhTI St. Petersburg

WP26 Detector Development
JINR Dubna

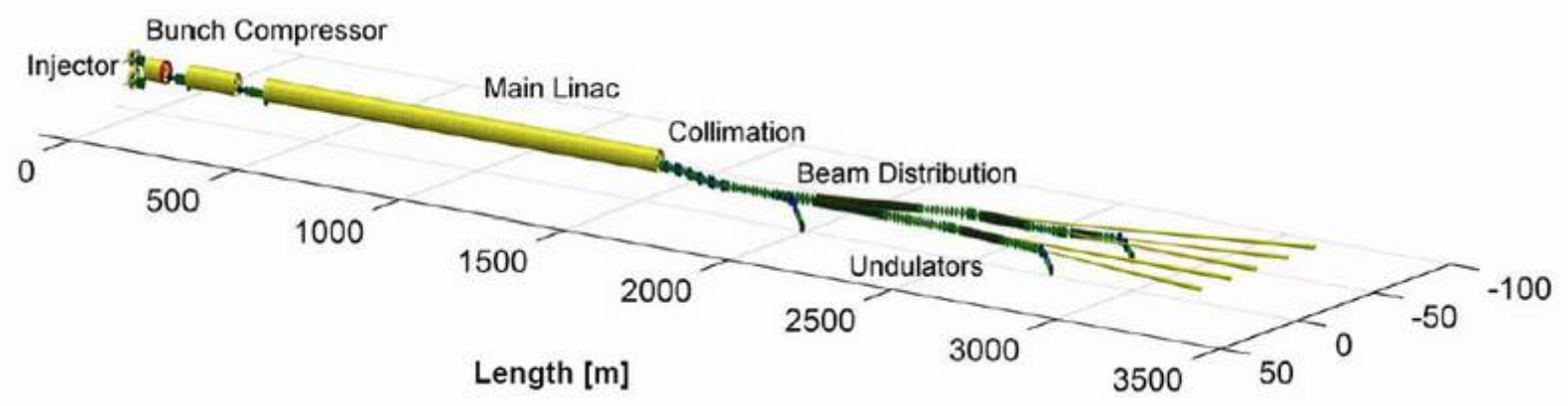
Some well know partners

&

a new management.

European XFEL

Accelerator layout



- 100 accelerator modules

- 800 accelerator cavities
- 1.3 Ghz / 23.6 MV/m

- 25 RF station 5.2 MW each

European XFEL

Start XFEL March 2009

European XFEL

Tunnel engineering

European XFEL

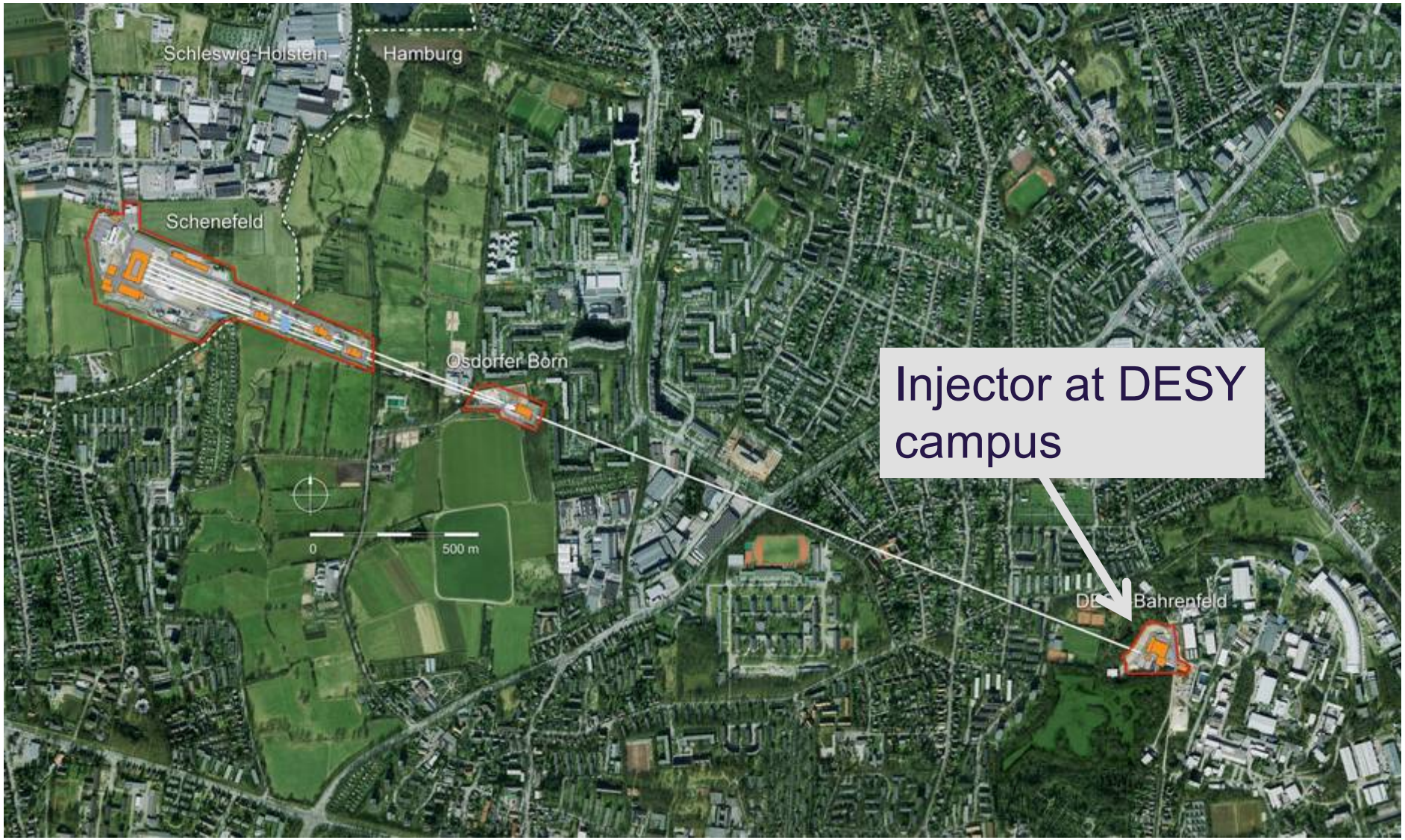
Tunnel engineering

European XFEL

Tunnel is finished 2013

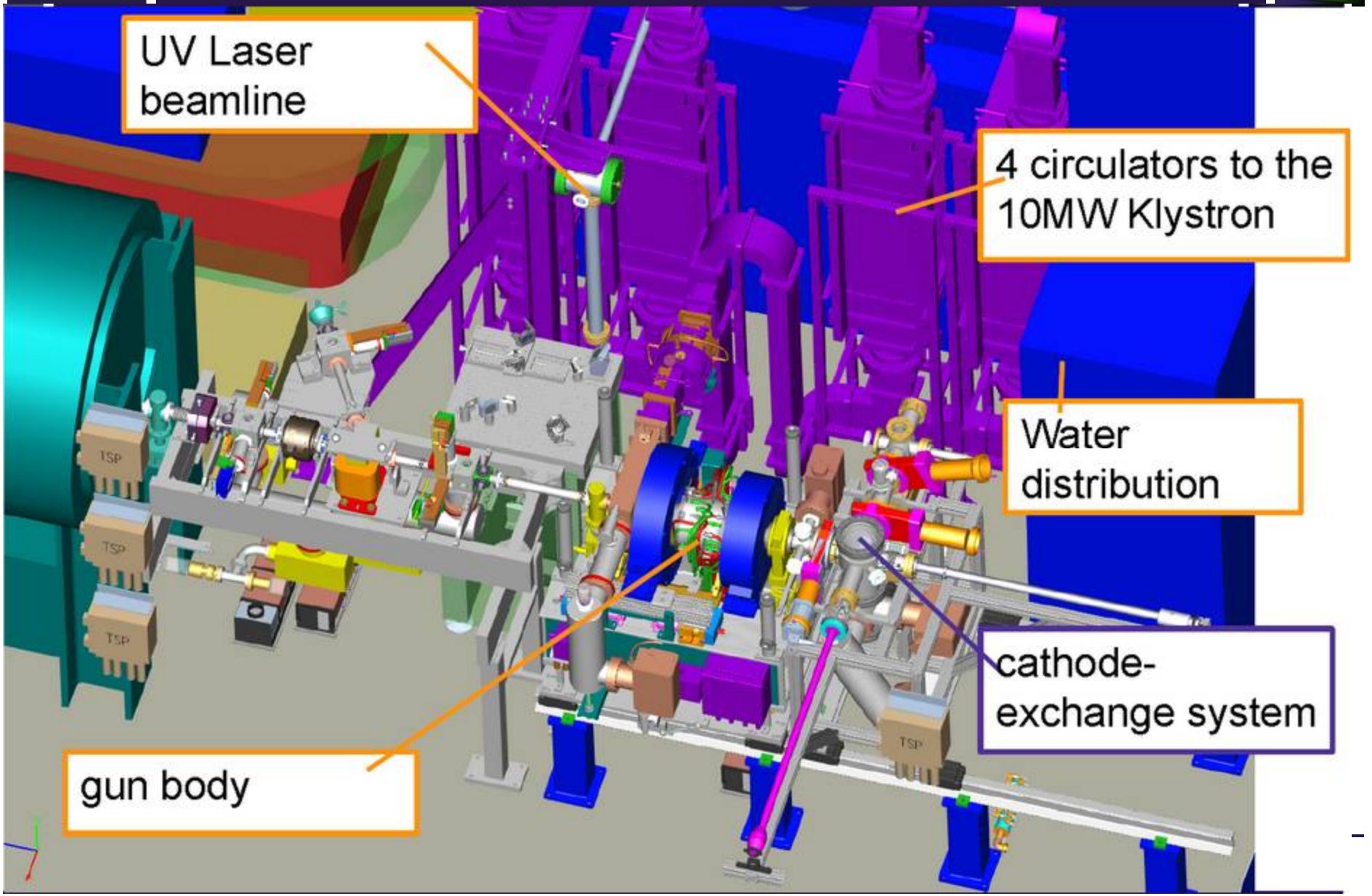
European XFEL

Main components of the accelerator - Gun



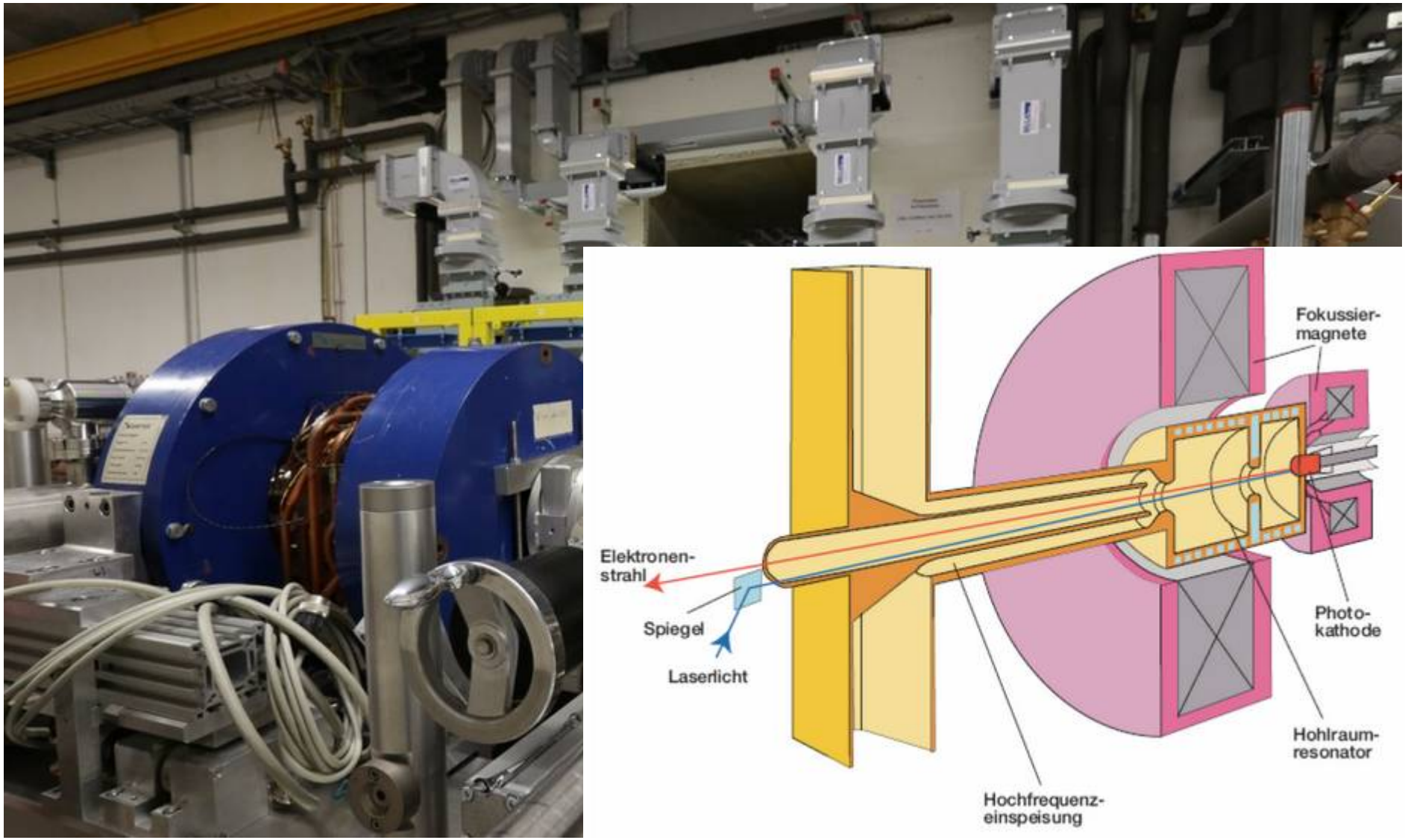
European XFEL

XFEL - Gun



European XFEL

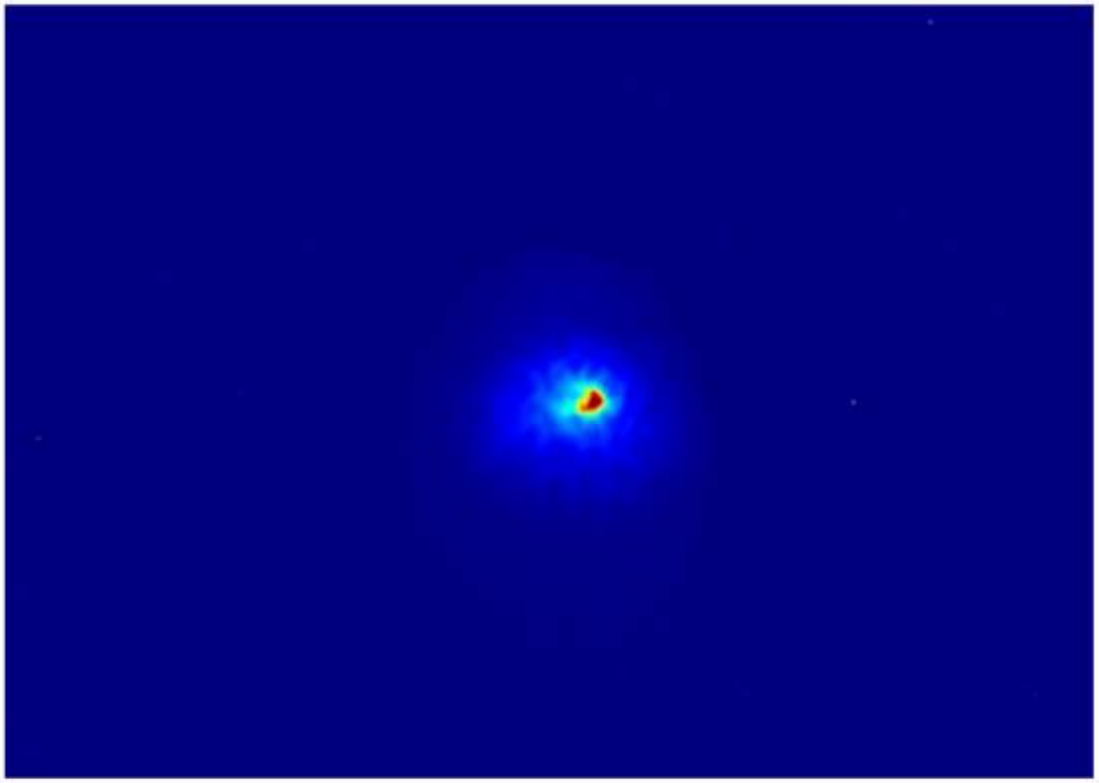
XFEL RF Gun Commissioning



European XFEL

XFEL – Gun at work

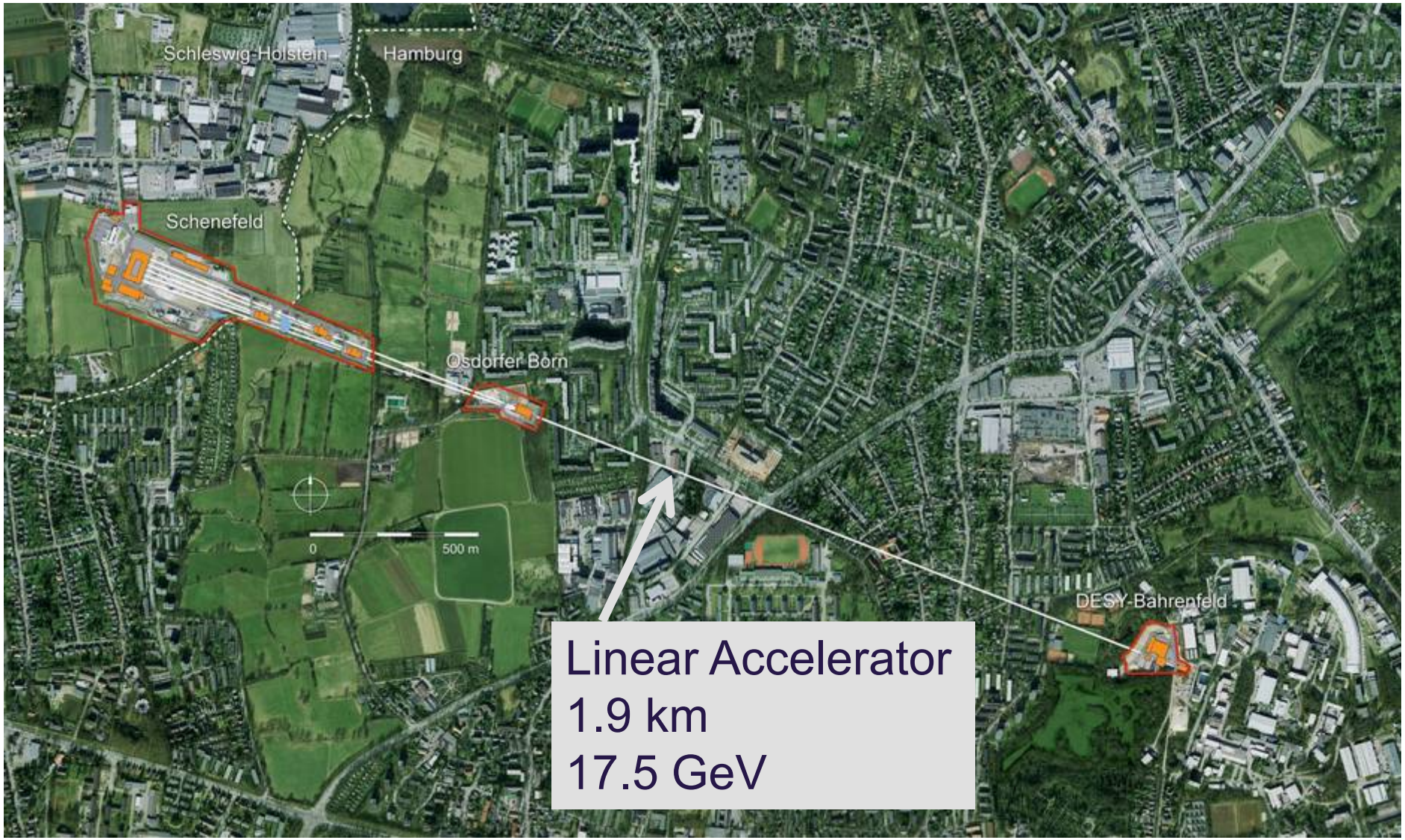
February 10th : First photo elektrons at XFEL !



Screen picture of the first photo electrons at XFEL –
3mm Aperture, 20 Bunche, 10 Hz, ca. 2nC

European XFEL

Main components of the accelerator - Linac



European XFEL

LINAC Tunnel February 2013


TUNNEL FÜR DEN
LINEARBESCHLEUNIGER - JANUAR 2015

European XFEL

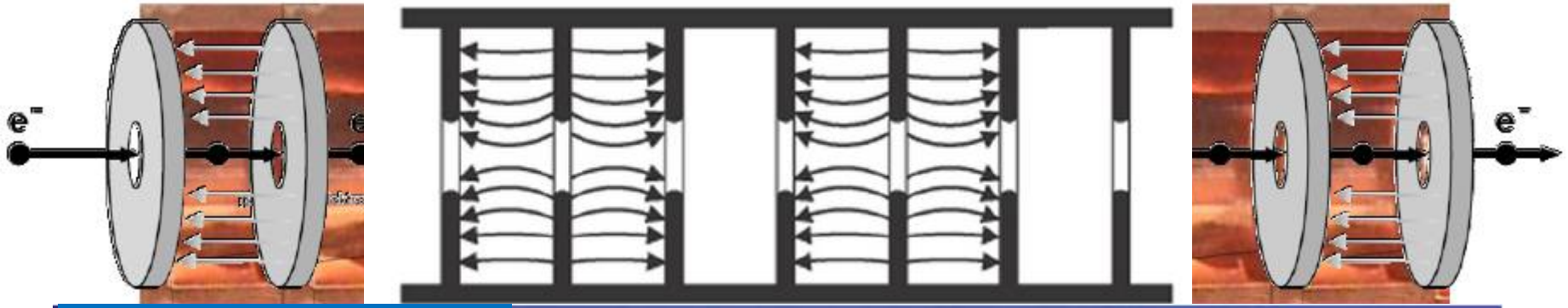
Superconductive Cavities

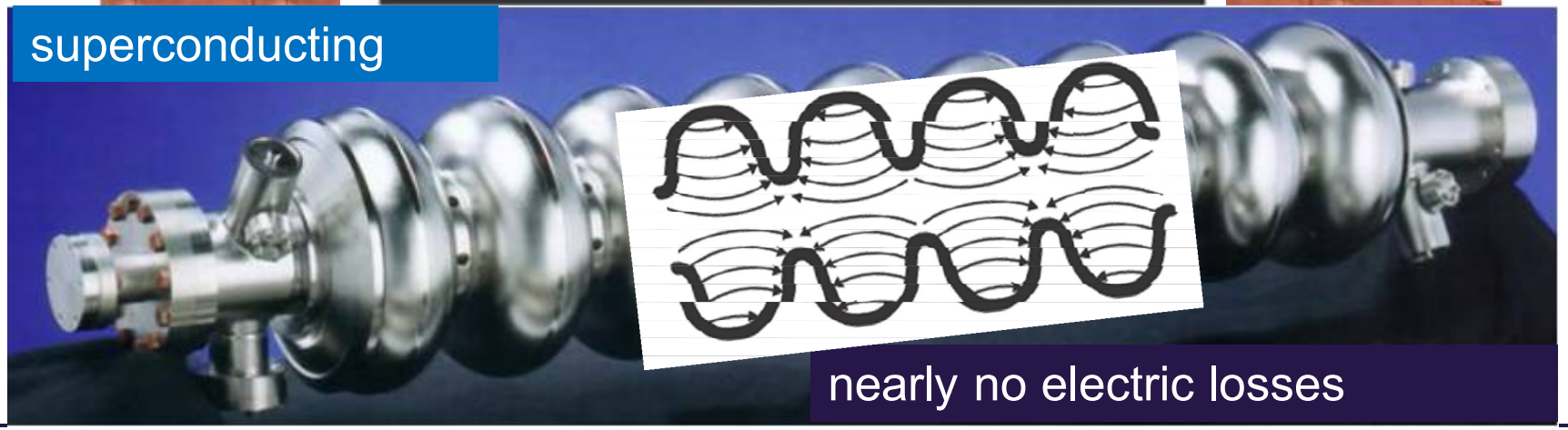
Why superconductive cavities are everybody's darling ????

European XFEL

Warm and Cold Cavities

- Simple trick: apply high frequent alternating field
- Move the accelerating electric field *with* the electrons
- Electrons always attracted from the positive plate in front
- Therefore acceleration over long distances possible

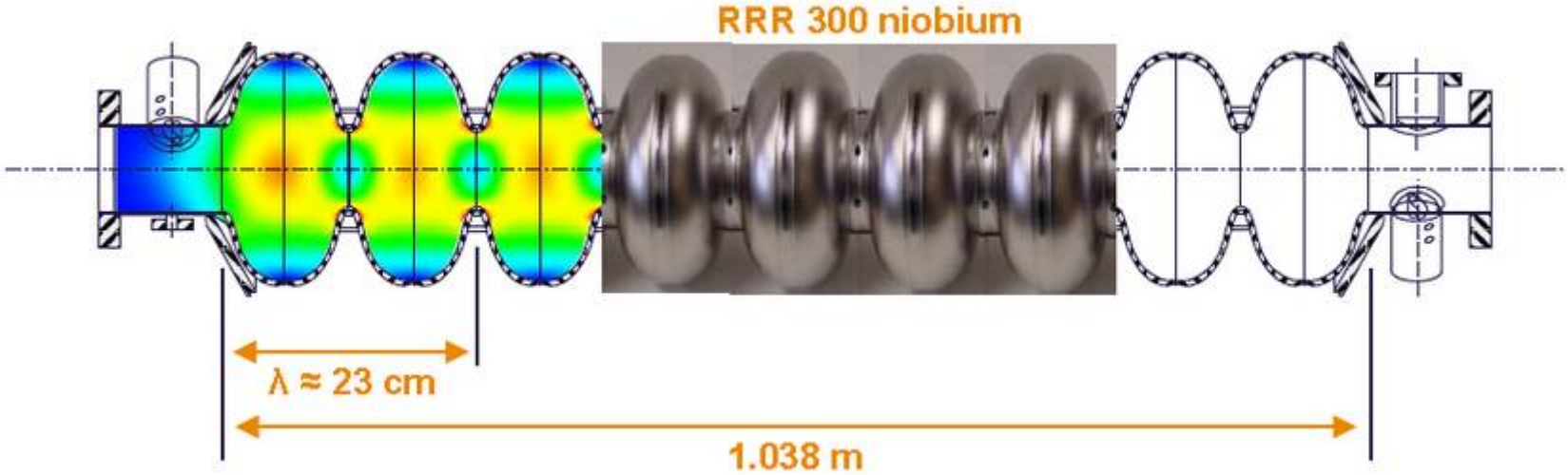




European XFEL

Cavity - Material

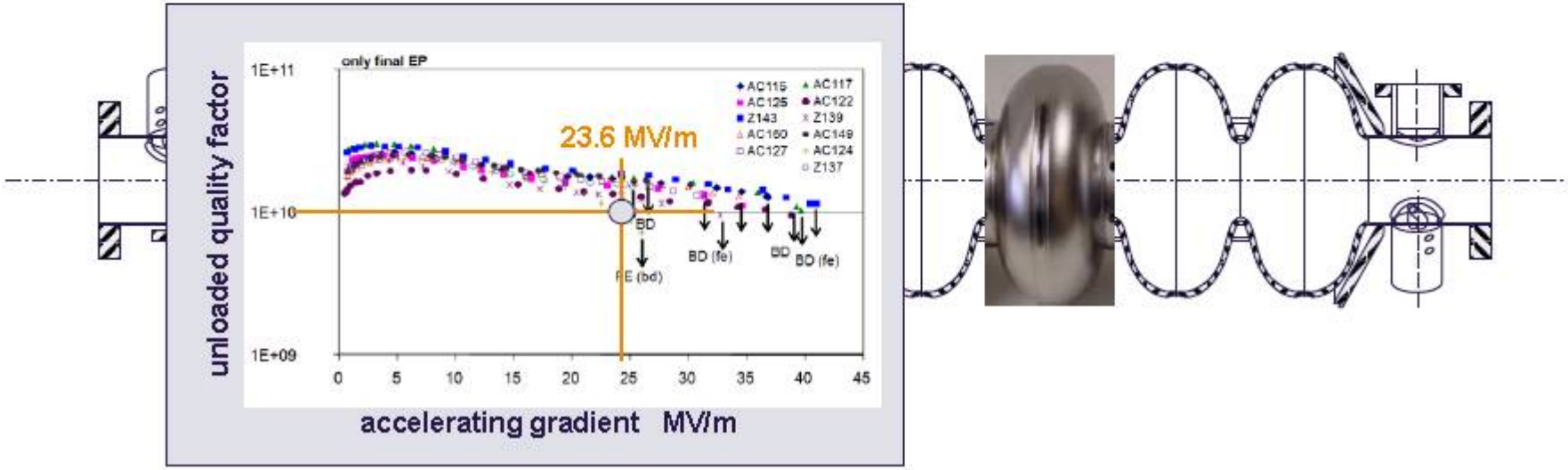
cavity material		RRR 300 niobium
type of accelerating structure		standing wave
accelerating mode		TM010, π-mode
fundamental frequency	f_{RF} [MHz]	1,300
active length	L [m]	1.038
nominal gradient	E_{acc} [MV/m]	23.6
quality factor	Q_0	$>10^{10}$
cell-to-cell coupling	K_{cc} [%]	1.87
iris diameter	[mm]	70



European XFEL

Cavity – E gradient

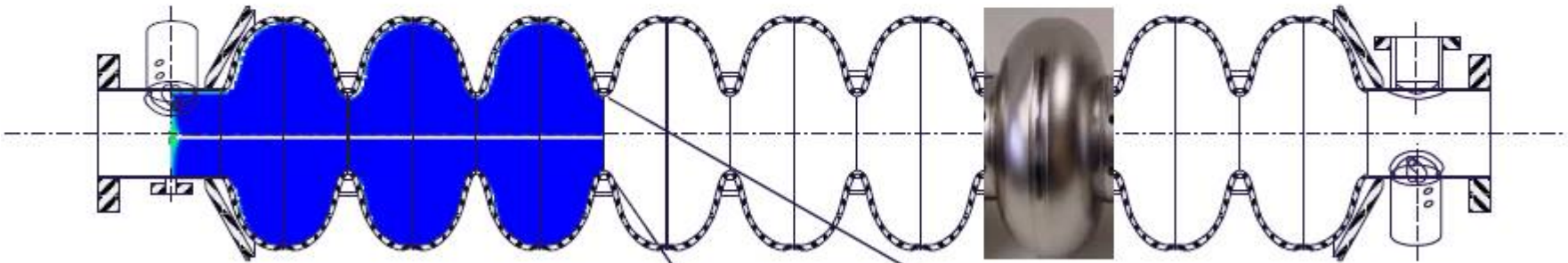
cavity material		RRR 300 niobium
type of accelerating structure		standing wave
accelerating mode		TM010, π-mode
fundamental frequency	f_{RF} [MHz]	1,300
active length	L [m]	1.038
nominal gradient	E_{acc} [MV/m]	23.6
quality factor	Q_0	$>10^{10}$
cell-to-cell coupling	K_{cc} [%]	1.87
iris diameter	[mm]	70



European XFEL

Cavity - Geometry

cavity material		RRR 300 niobium
type of accelerating structure		standing wave
accelerating mode		TM010, π-mode
fundamental frequency	f_{RF} [MHz]	1,300
active length	L [m]	1.038
nominal gradient	E_{acc} [MV/m]	23.6
quality factor	Q_0	$>10^{10}$
cell-to-cell coupling	K_{cc} [%]	1.87
iris diameter	[mm]	70



Wakefield excitation is reduced

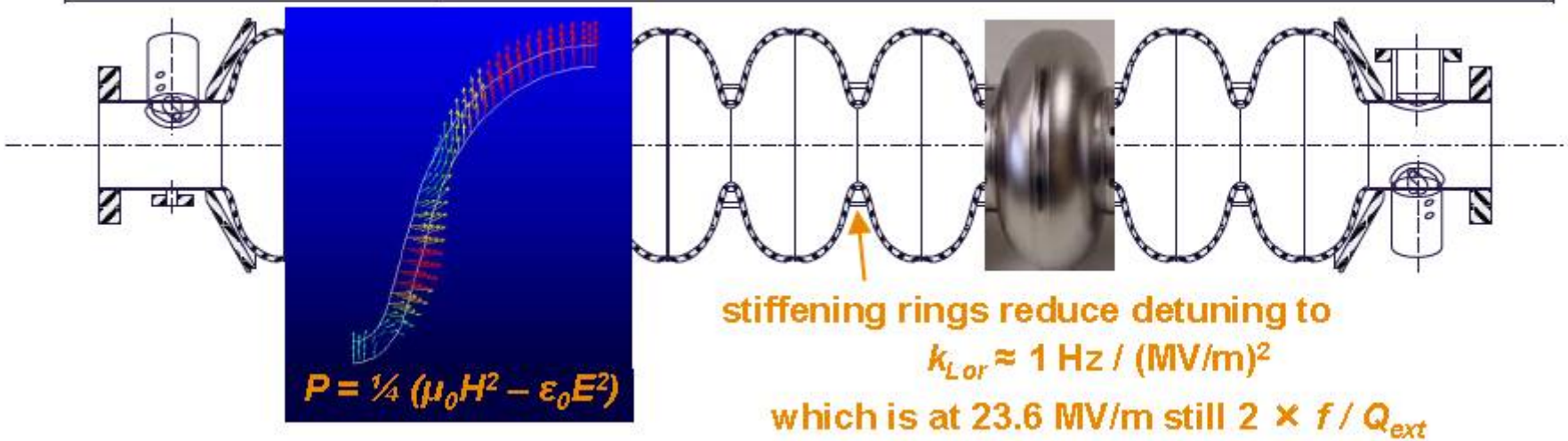
$W_{\parallel} \sim f^2$ $W_{\perp} \sim f^3$

70 mm

European XFEL

Cavity - Frequency

R/Q	[Ω]	1,036
E_{peak} / E_{acc}		2.0
B_{peak} / E_{acc}	[mT / MV/m]	4.26
Tuning range	[kHz]	± 300
$\Delta f / \Delta L$	[kHz / mm]	315
Lorentz force detuning constant	K_{Lor} [Hz / (MV/m)^2)	1
Q_{ext} of input coupler		4.6 × 10^6
cavity bandwidth f / Q_{ext}	[Hz] FWHM	283
fill time	[ms]	780
number of HOM couplers		2

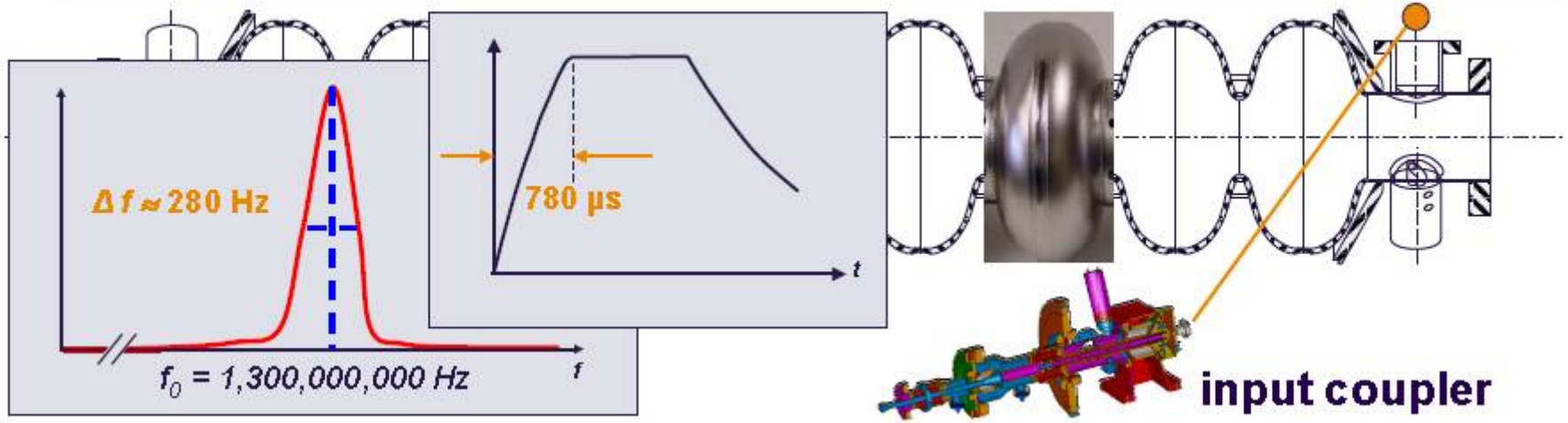


stiffening rings reduce detuning to
$k_{Lor} \approx 1$ Hz / (MV/m)^2
which is at 23.6 MV/m still 2 × f / Q_{ext}

European XFEL

Cavity - Bandwith

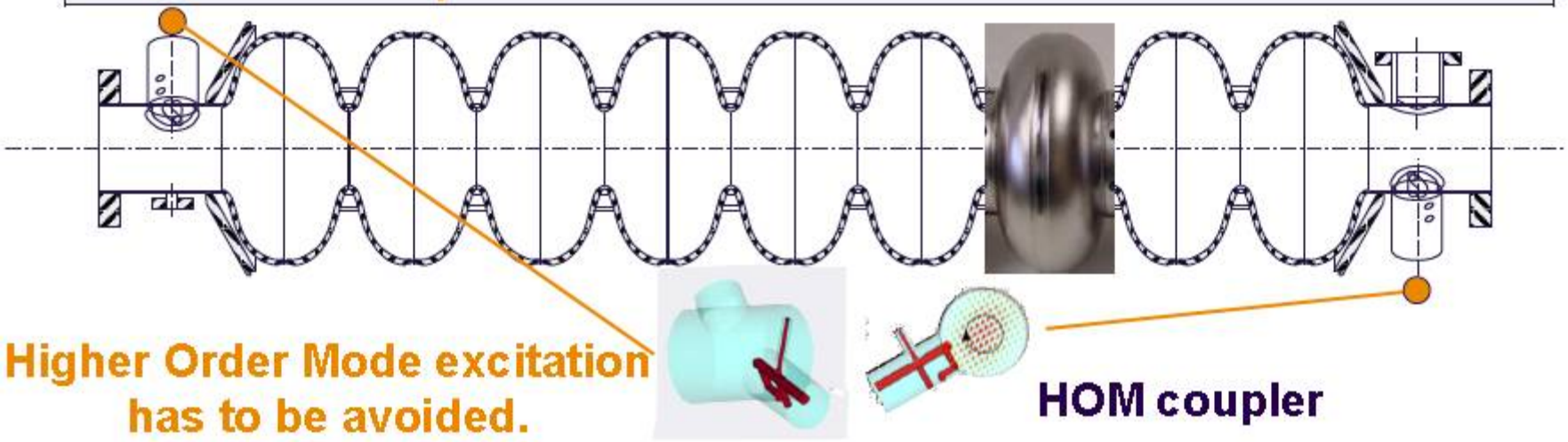
R/Q	[Ω]	1,036
E_{peak} / E_{acc}		2.0
B_{peak} / E_{acc}	[mT / MV/m]	4.26
Tuning range	[kHz]	± 300
$\Delta f / \Delta L$	[kHz / mm]	315
Lorentz force detuning constant	K_{Lor} [Hz / (MV/m)^2)	1
Q_{ext} of input coupler		4.6 × 10^6
cavity bandwidth f / Q_{ext}	[Hz] FWHM	283
fill time	[ms]	780
number of HOM couplers		2



European XFEL

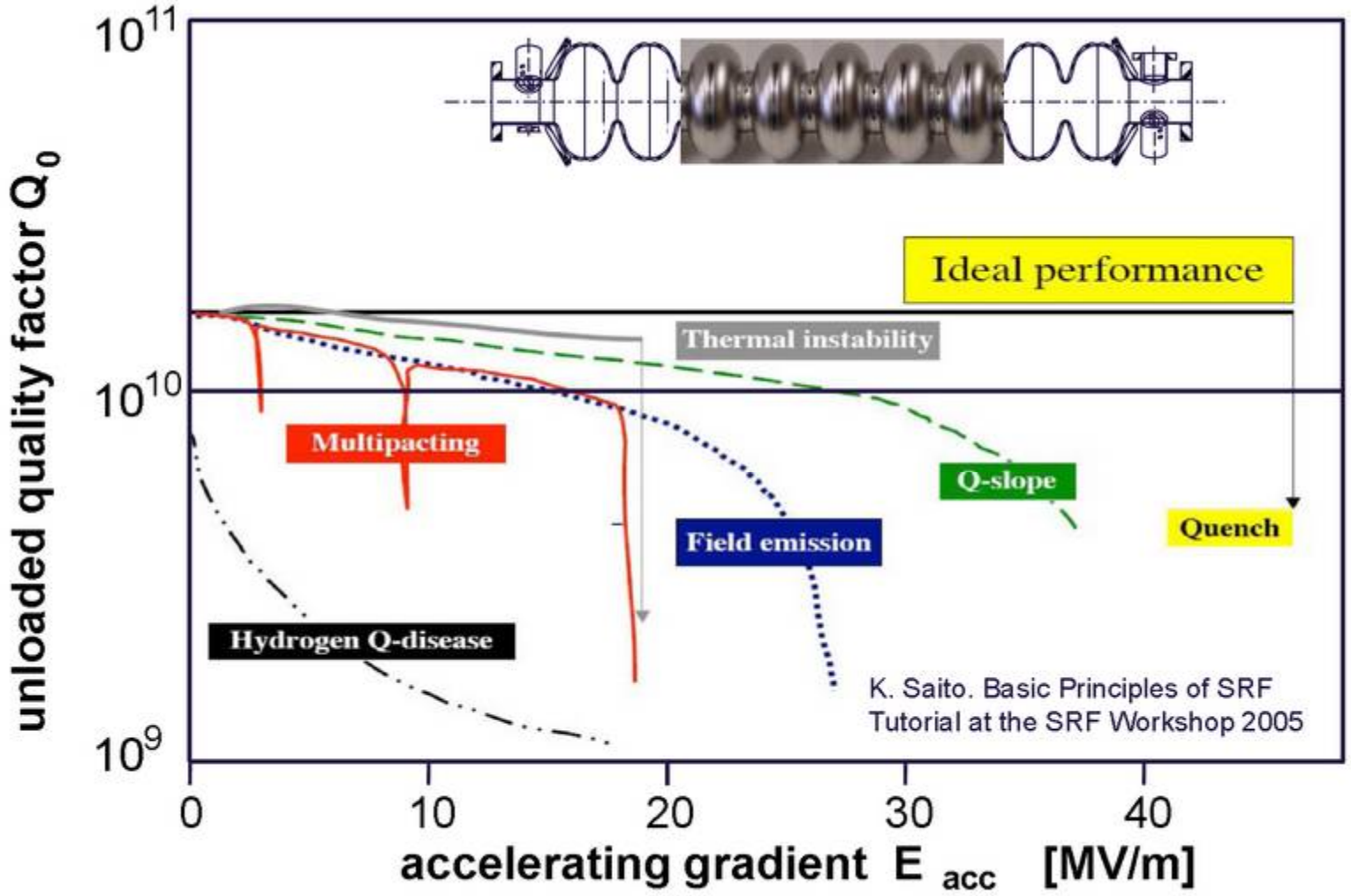
Cavity - Higher Modes

R/Q	[Ω]	1,036
E_{peak} / E_{acc}		2.0
B_{peak} / E_{acc}	[mT / MV/m]	4.26
Tuning range	[kHz]	± 300
$\Delta f / \Delta L$	[kHz / mm]	315
Lorentz force detuning constant	K_{Lor} [Hz / (MV/m)^2)	1
Q_{ext} of input coupler		4.6 × 10^6
cavity bandwidth f / Q_{ext}	[Hz] FWHM	283
fill time	[ms]	780
number of HOM couplers		2



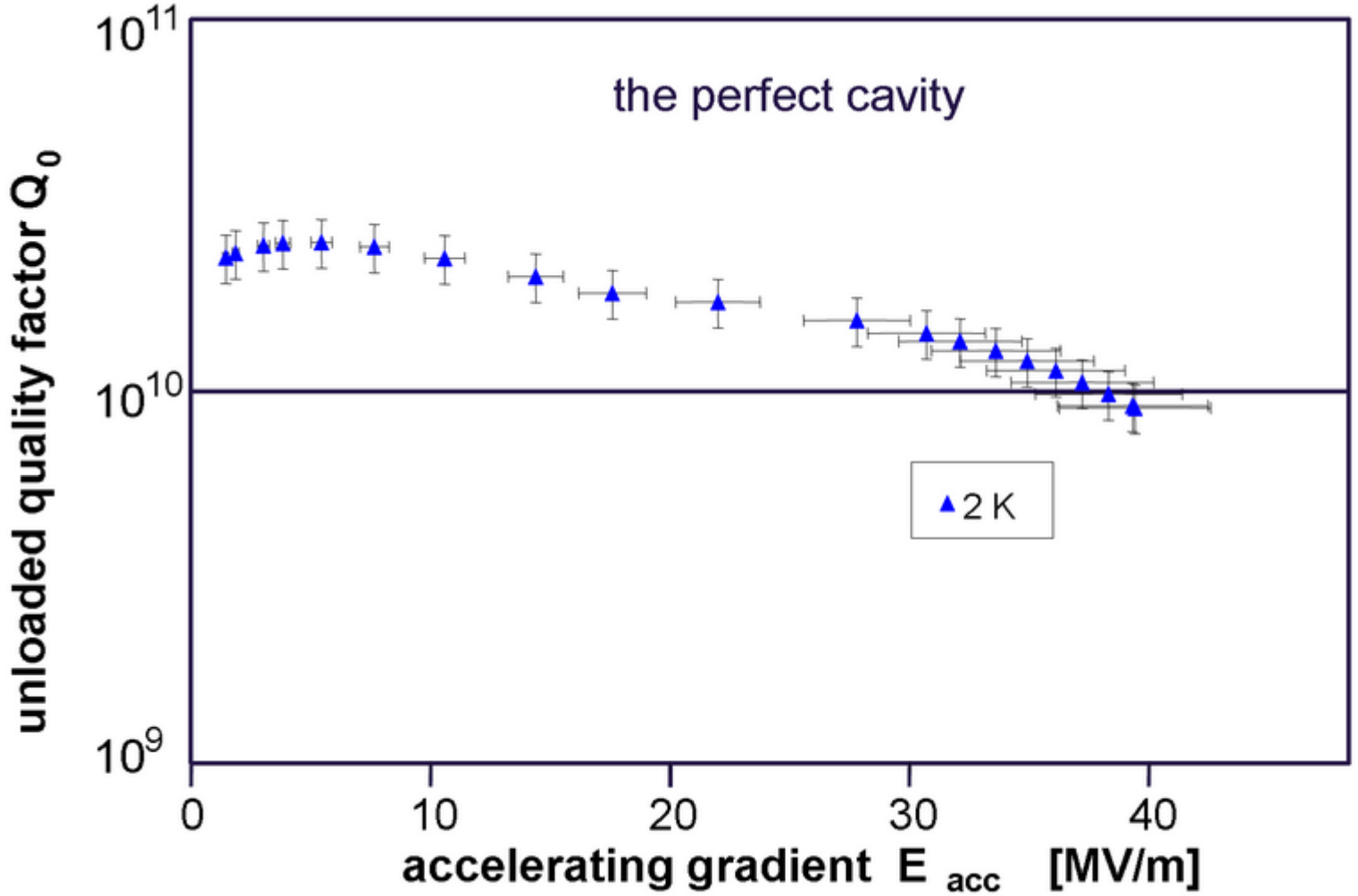
European XFEL

Here the famous Q vs E behaviour of Cavities



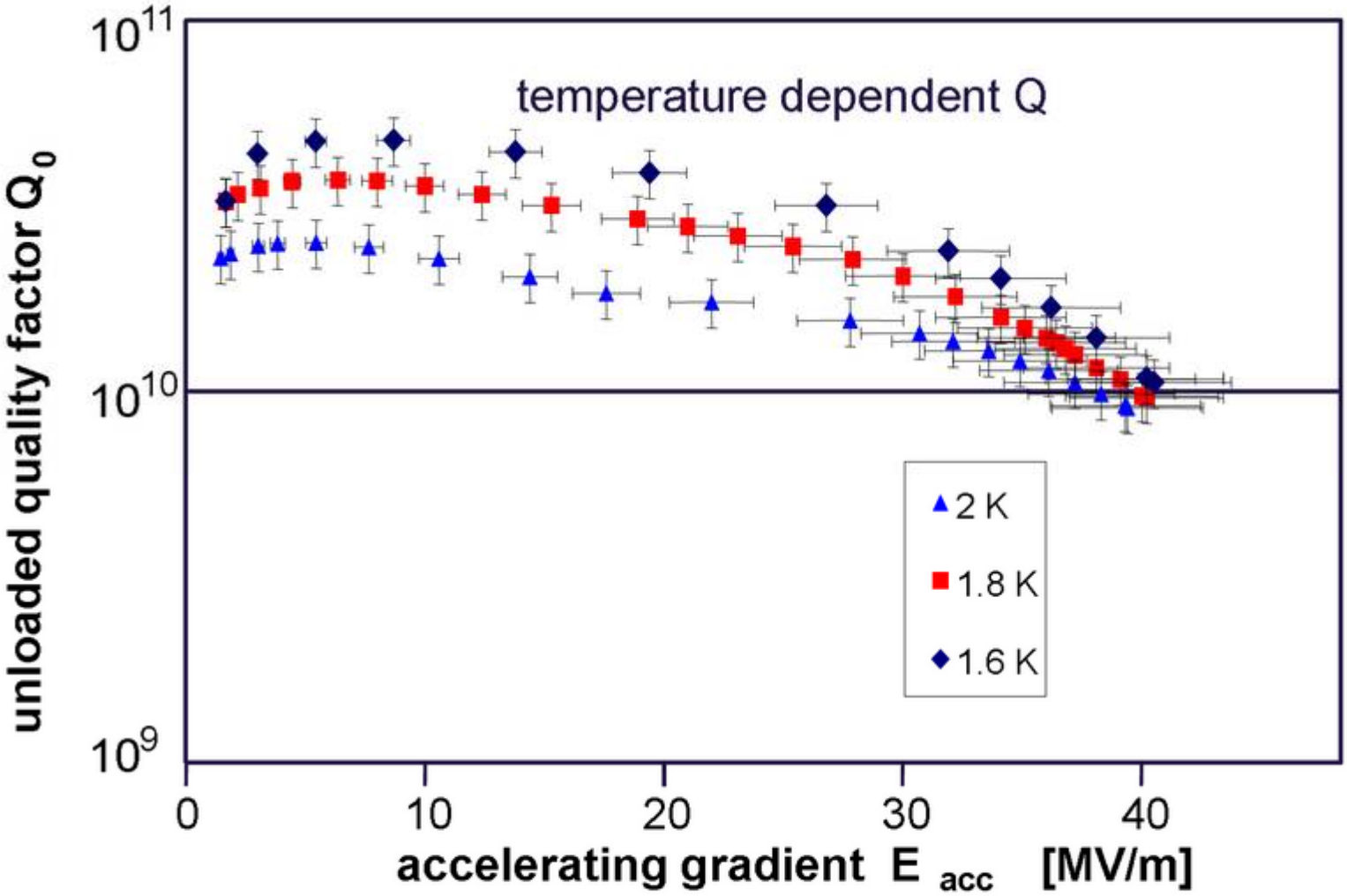
European XFEL

Cavity as it should be …..



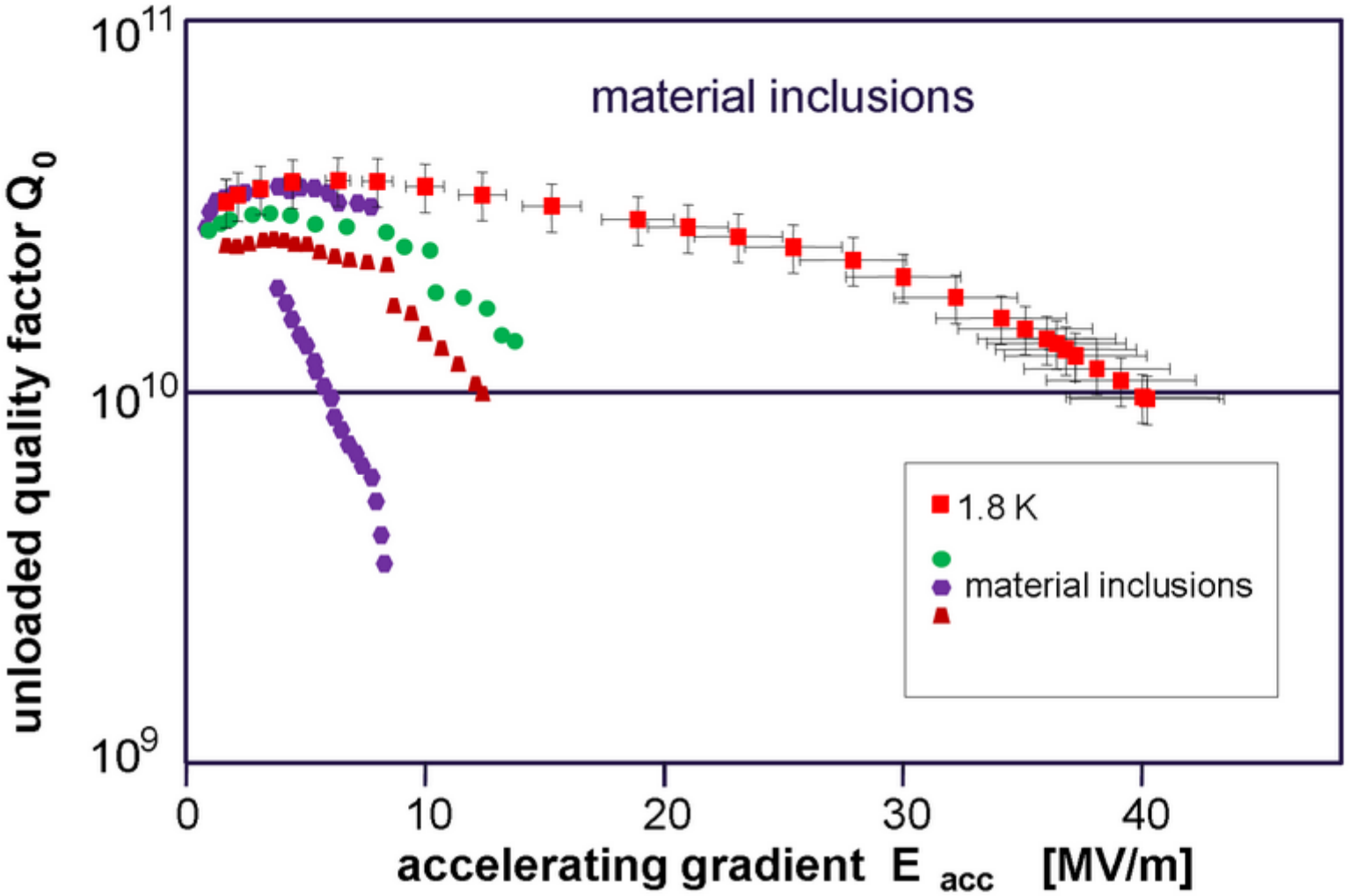
European XFEL

Temperature is cool



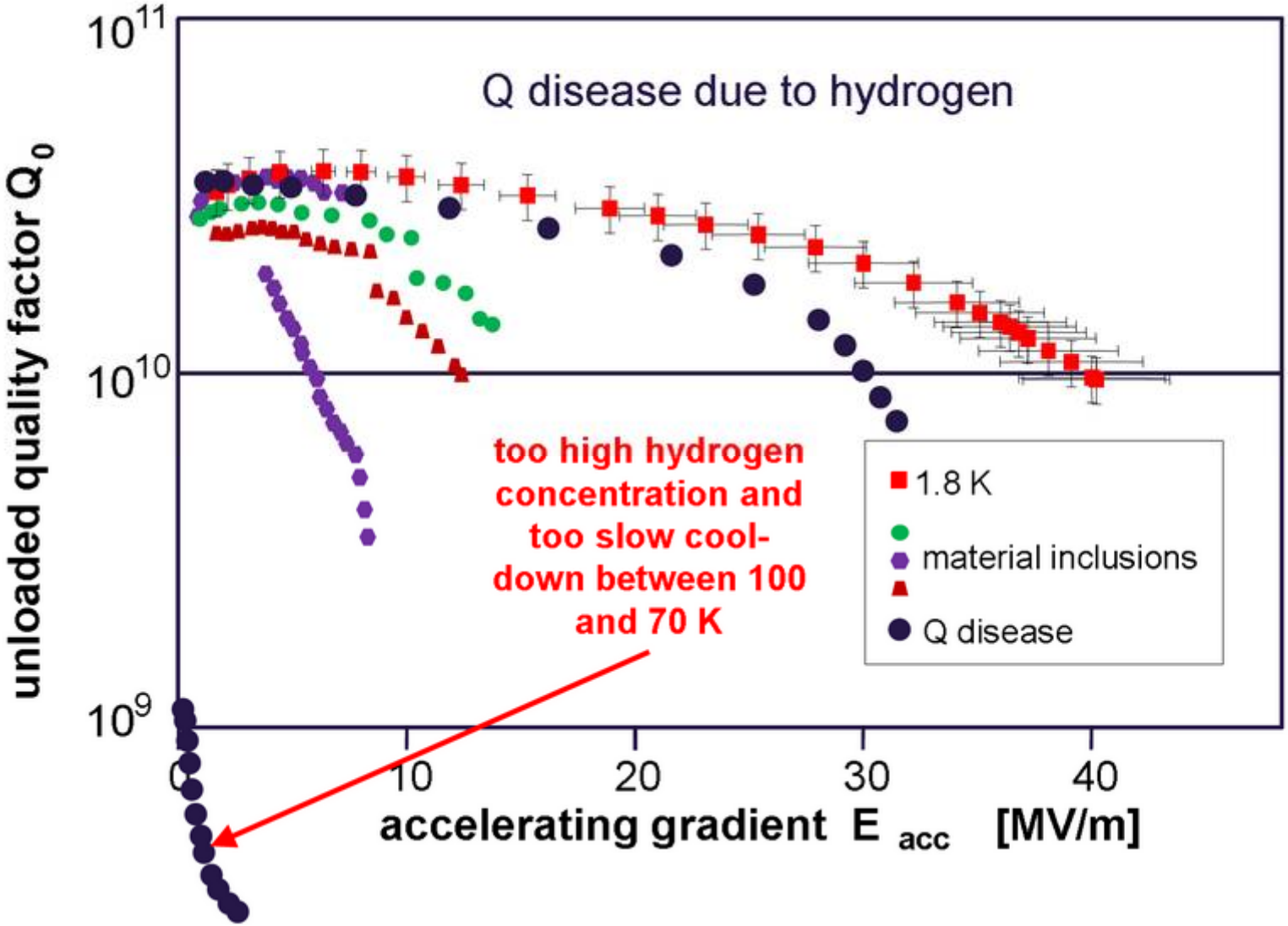
European XFEL

Impurities, contaminations are bad



European XFEL

Hydrogen is a disaster



European XFEL

Production at Zanon (Italy)

European XFEL

Cleaning at Zanon (Italy)

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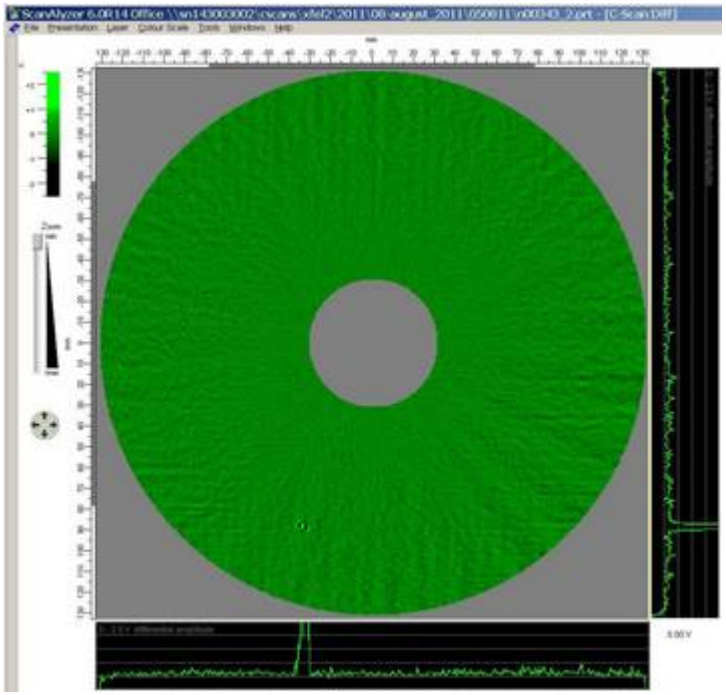
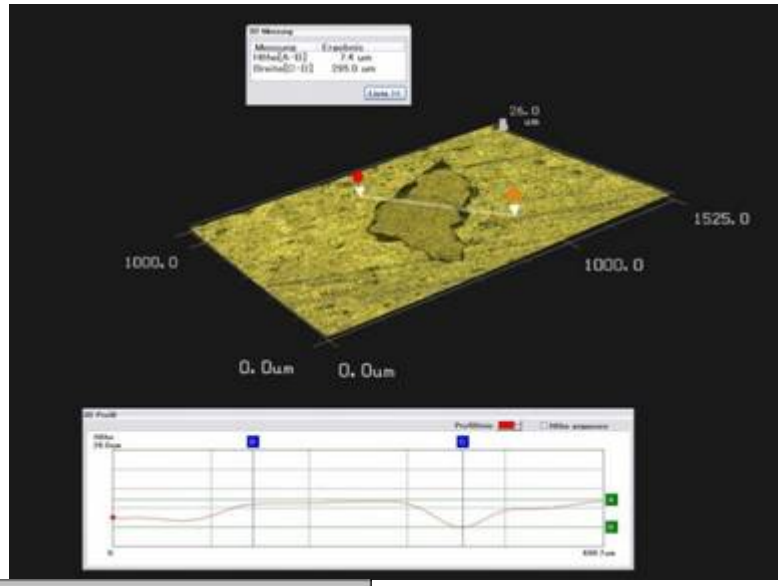
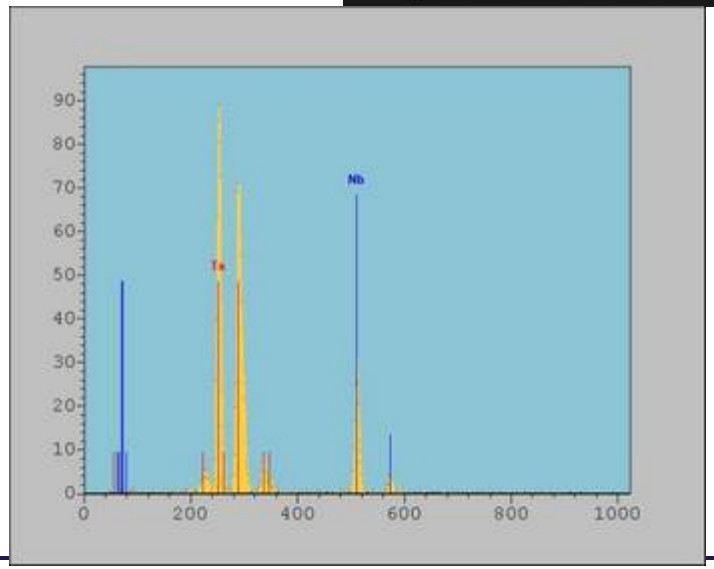
Tantalum Cluster in the Niobium Cavity



- Eddy current

- 3D – microscope





- Mass - spectroscopy

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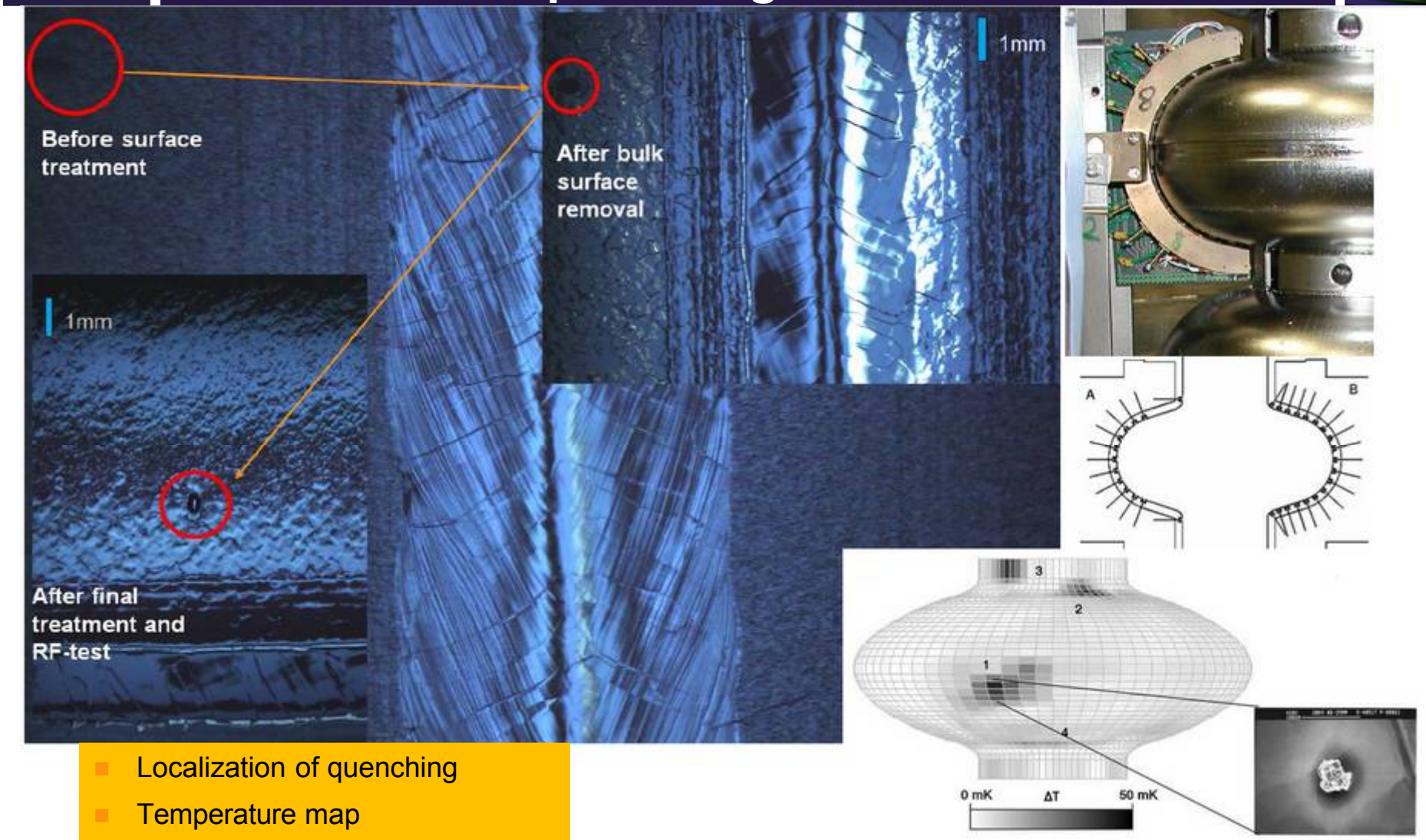
Localization of quenching



- Localization of quenching
- Temperature map
- Optical inspection

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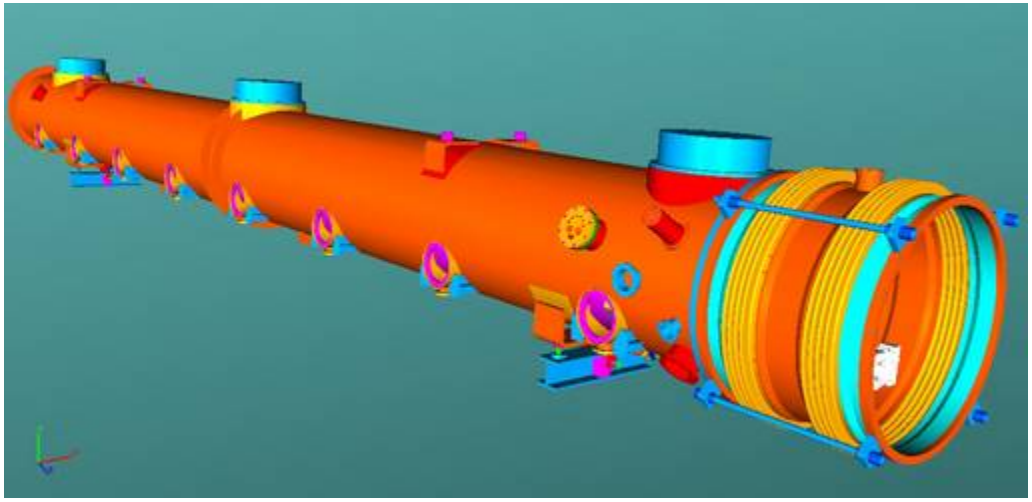
Assembling of Accelerator Modules



- Helium vessel fabrication
- Titanium Tube and 2-phase line

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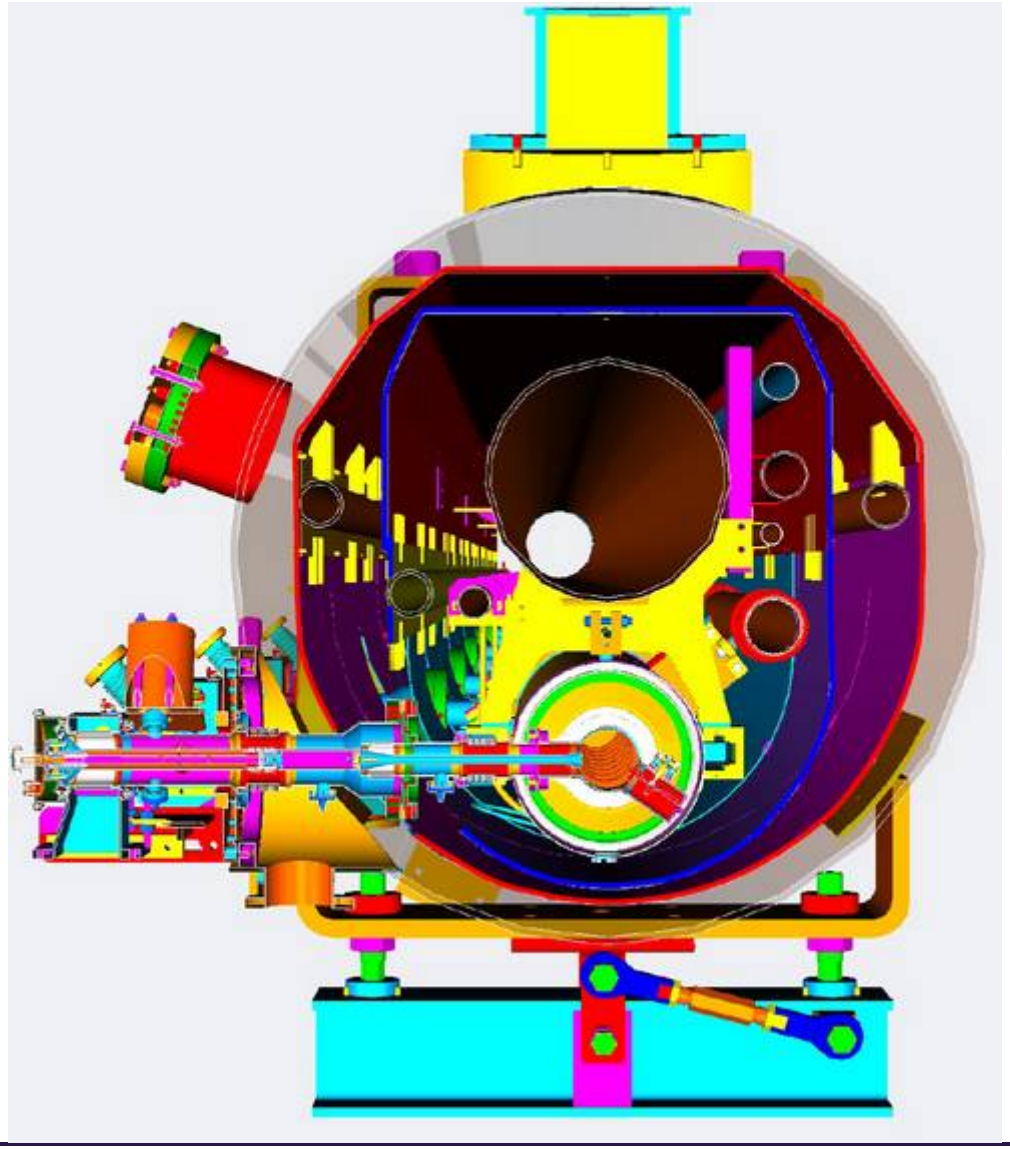
Accelerator Module (Cryomodule)



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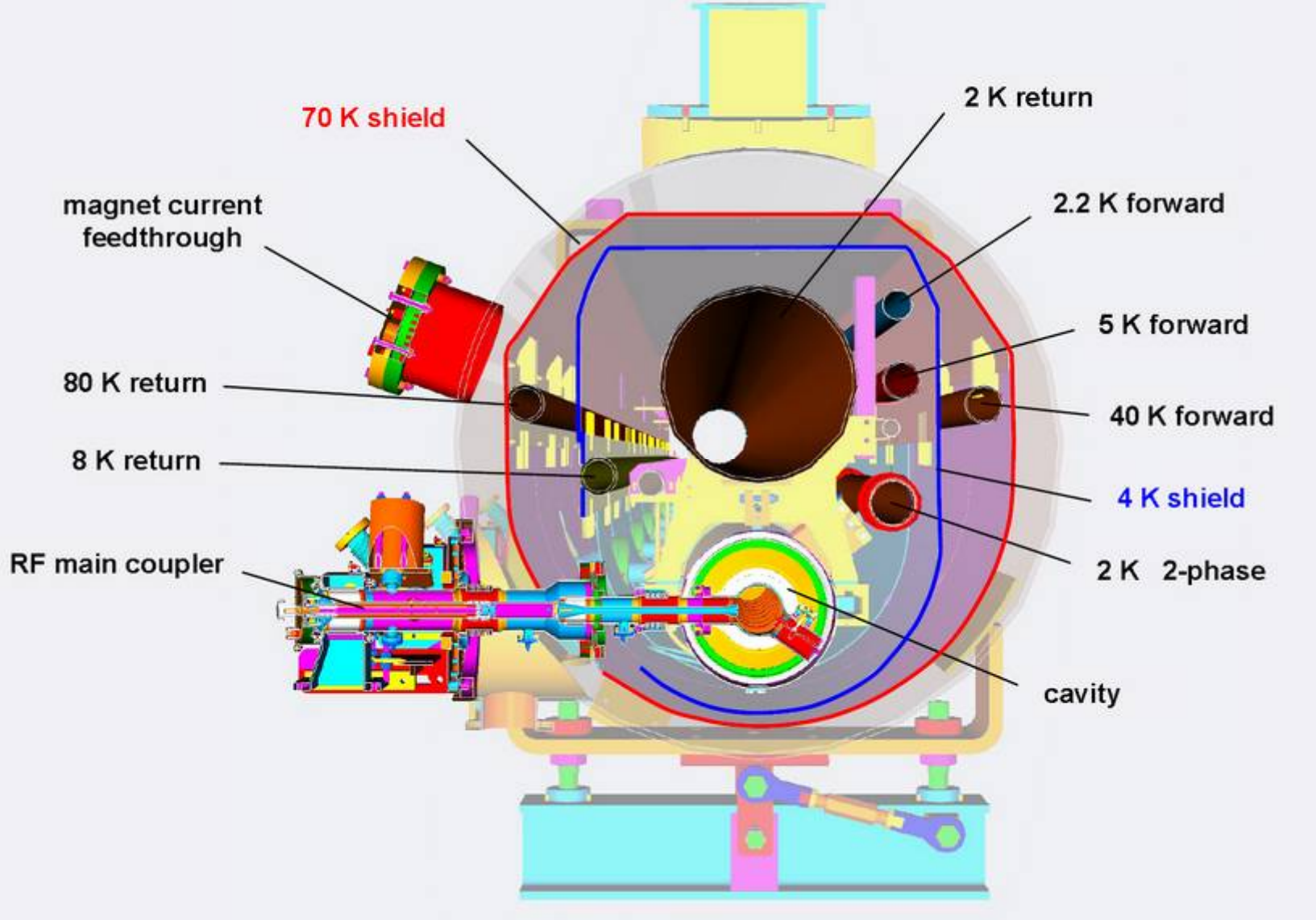
Accelerator Module (Cryomodule)



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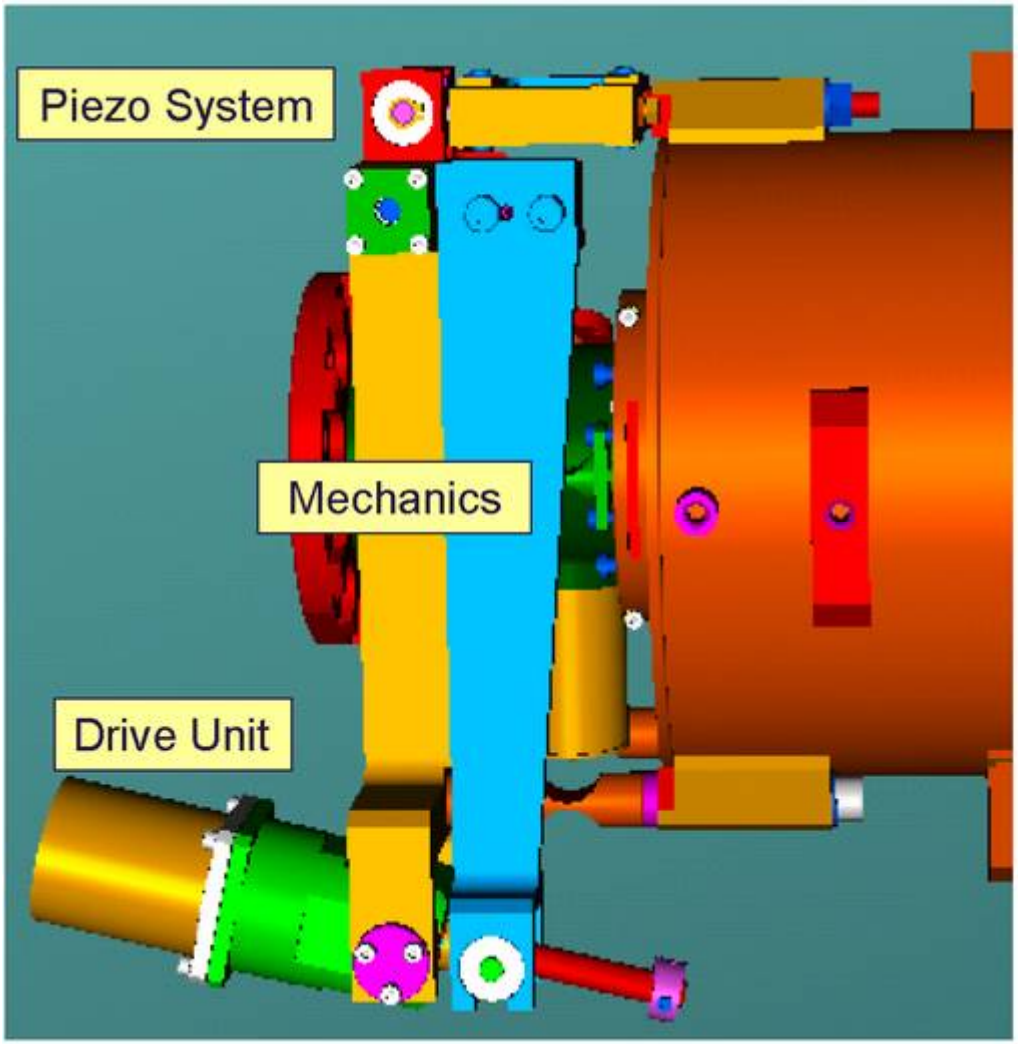
Frequency Tuner



- **Mechanics:**
  - Series fabrication ongoing.
- **Drive unit:**
  - Documentation reports decided.
  - First units have FAT and been delivered to CEA and DESY.
  - Ramp up to series rate has been achieved.
- **Piezo system:**
  - Continuing tests of permanent FLASH setup.
  - Series production of fixtures ongoing.
- **QC testing:**
  - during module installation at Saclay (INFN contribution).

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Accelerator Module Test Facility – AMTF Hall

- New building especially designed and build for the test of the Accelerator modules.

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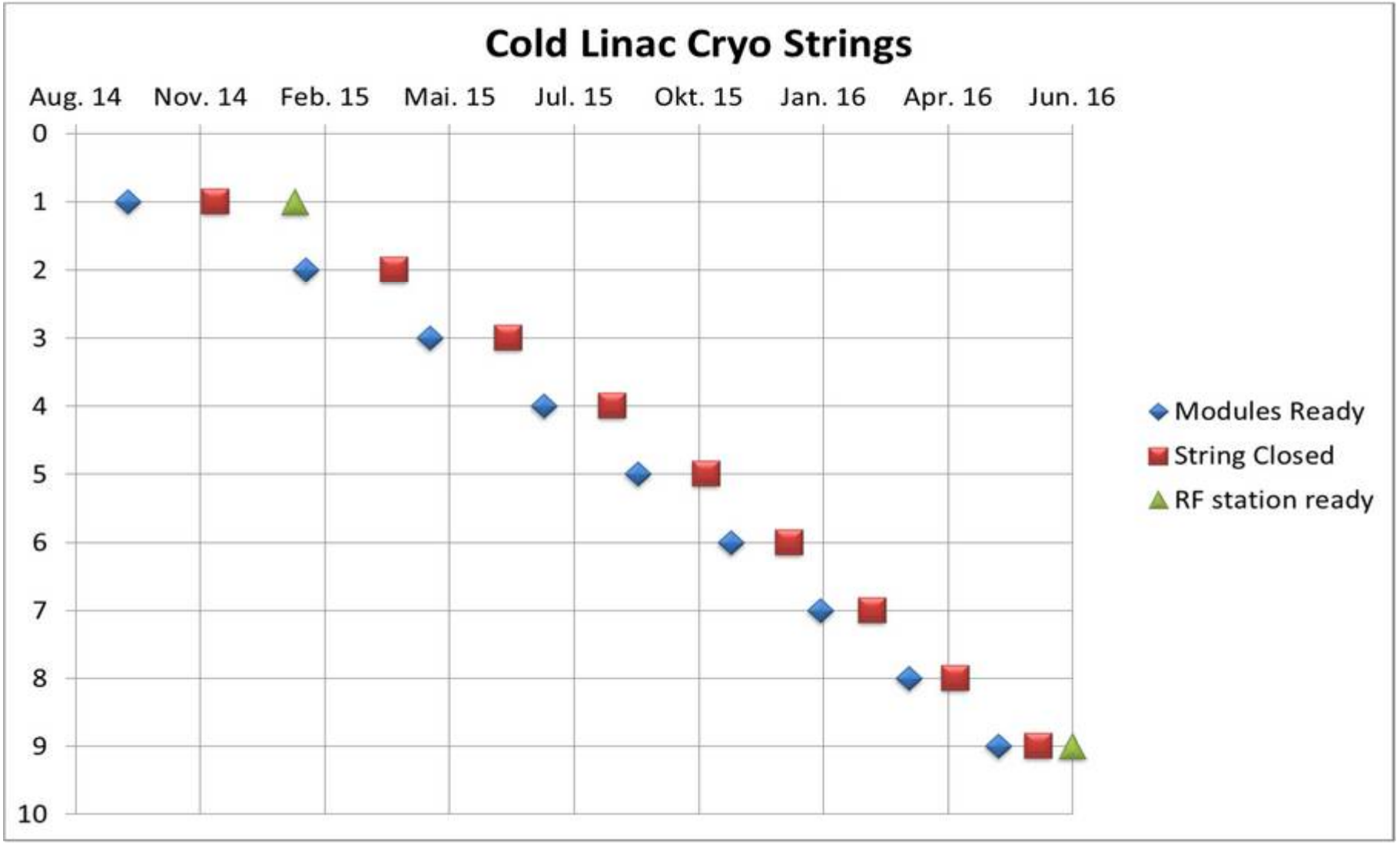
Installation Sequence



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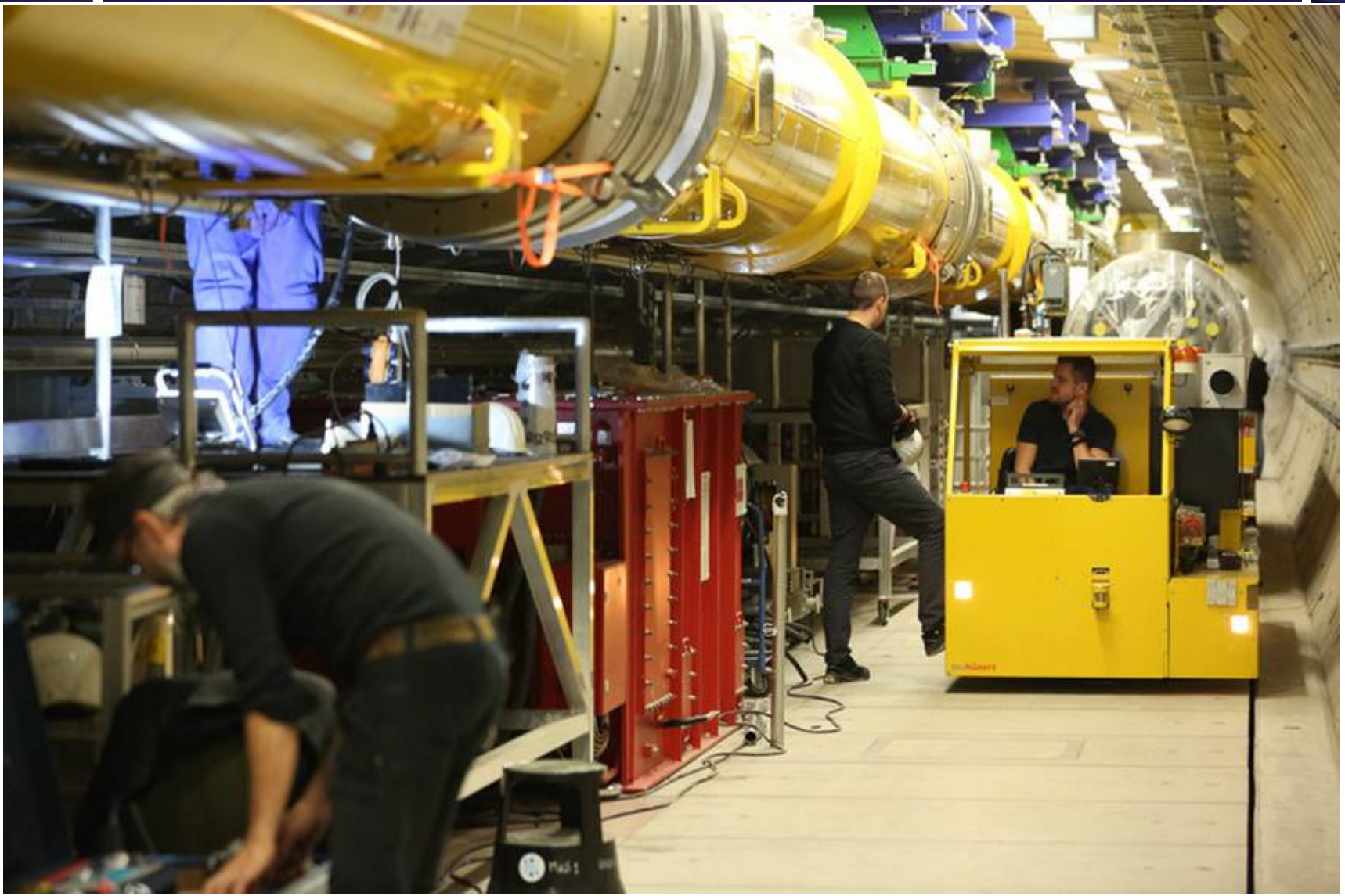
Linac tunnel installation



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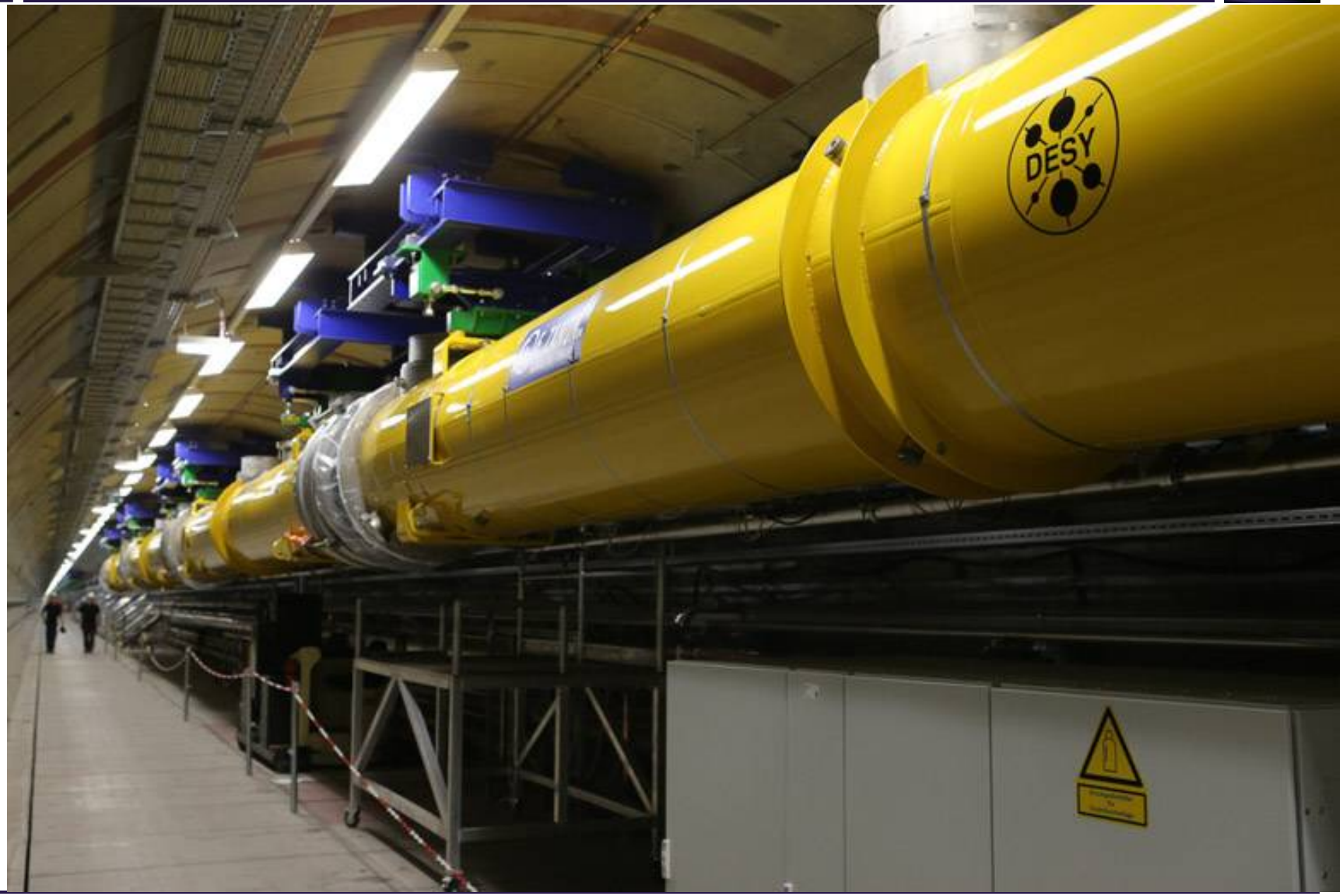
Linac tunnel with first modules installed



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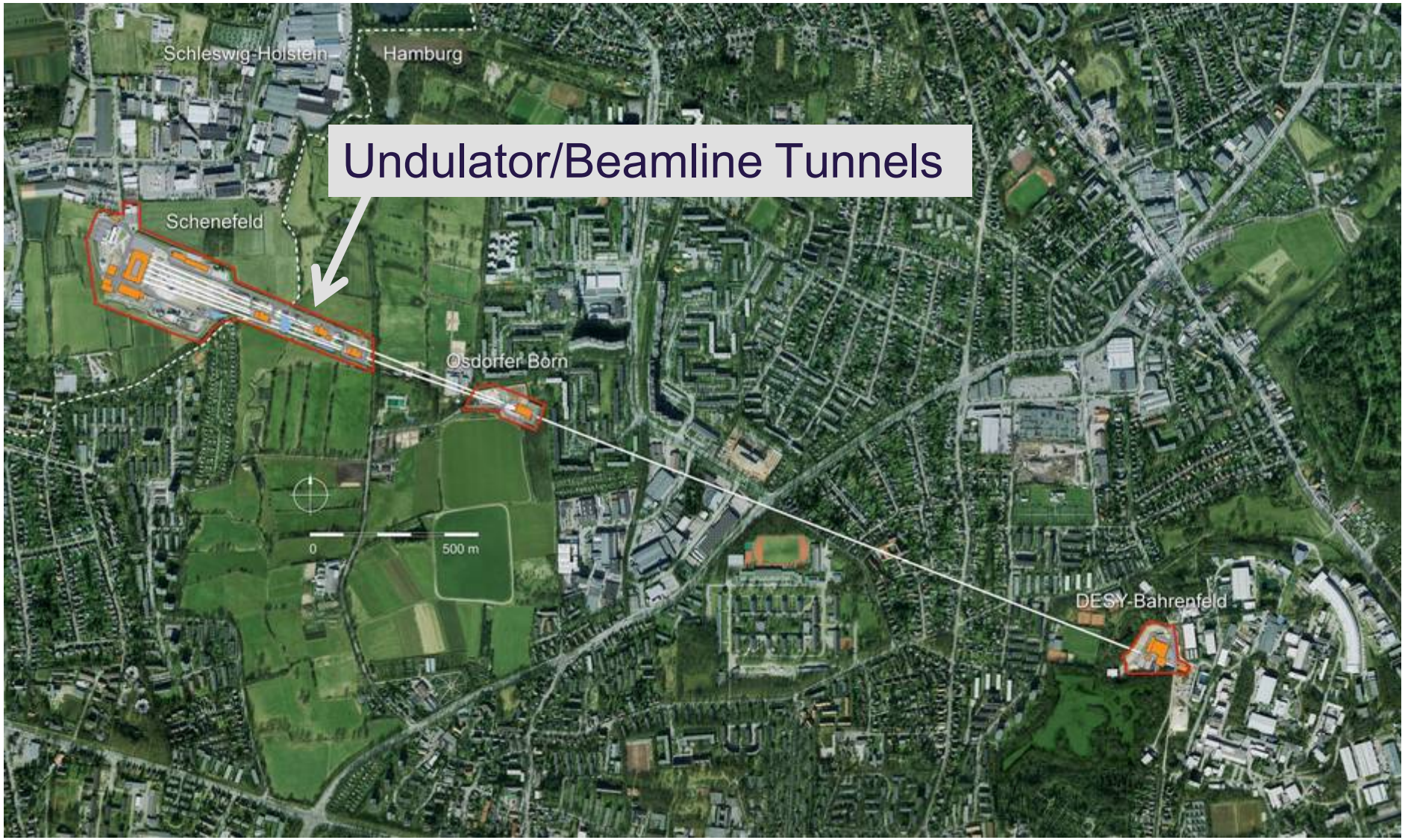
Almost 800 Magnets (produced at Efremov, Budker ….)

European XFEL

Main components of the accelerator - Undulators



European XFEL

Let there be light! Fiat flux! Да будет свет!

European XFEL

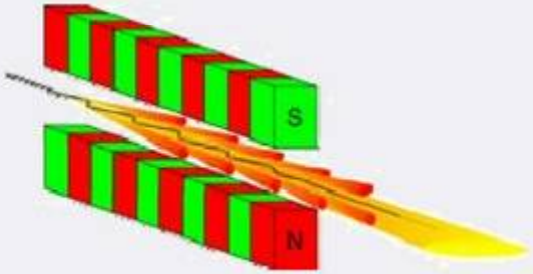
Free-Electron Laser - ingredients

A **Free-Electron Laser** is a light source exploiting the spontaneous and/or induced emission of a relativistic electron beam "guided" by the periodic and static magnetic field generated by an undulator (typ. 0.5 – 1 T).

Electron beam at relativistic energy

→ Energy (γ)
Current (I)
Emittance (ε)
Energy spread ($\delta\gamma$)
Dimensions (σ)

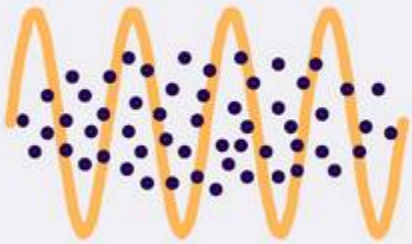
Undulator



Magnetic period (λ_u)
Magnetic strength (K)
Undulator length (L)

Electromagnetic field

co-propagating with the electron beam and **getting amplified** to the detriment of the electrons' kinetic energy



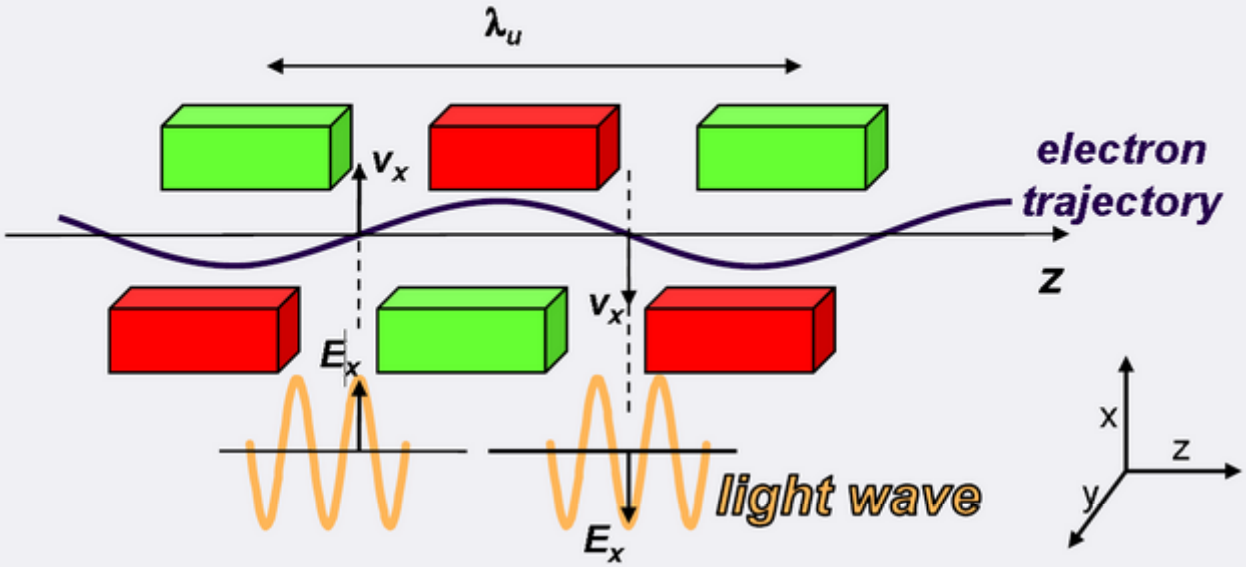
→ Wavelength (λ)
Power (P)

European XFEL

Self Amplified Spontaneous Emission (SASE)

light wave
the transversally accelerated electrons emit synchrotron radiation

slippage
electrons move slower than the co-propagating electromagnetic light wave



$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

- sustained energy transfer from the electron to the light wave is guaranteed if **the light wave slips** forward by $\lambda/2$ per half period of the electron trajectory, i.e. per half period of the undulator ($\lambda_u/2$)

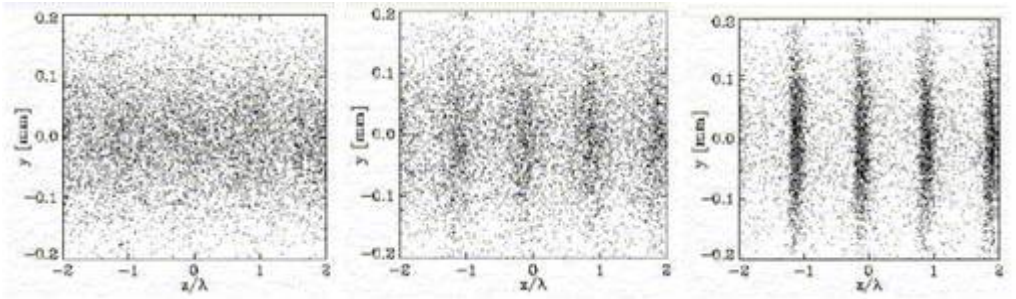
Condition for sustained energy transfer leads to exactly the same wavelength as in undulator radiation

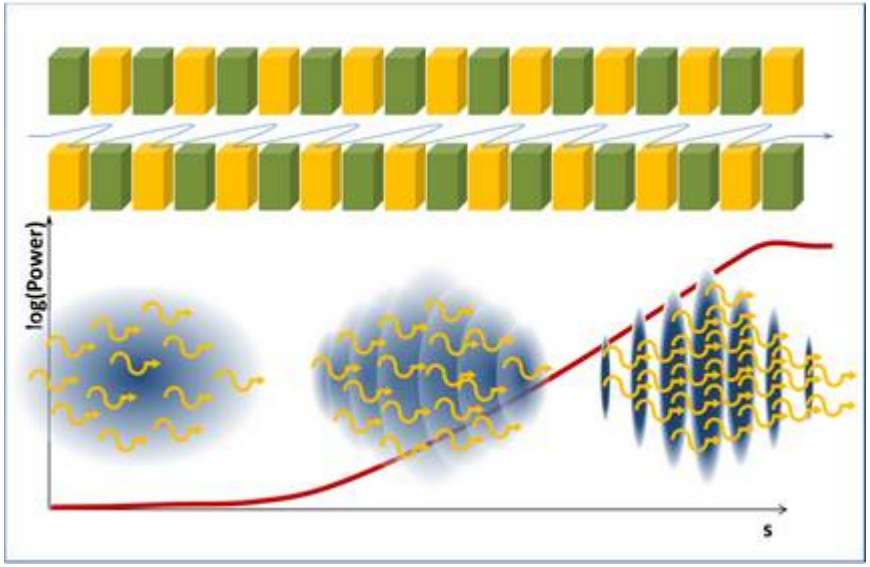
- this leads to **constructive interference** since the relative phase between the synchrotron radiation emitted by the electron and the co-propagating field remains constant

European XFEL

Self Amplified Spontaneous Emission (SASE)

- Electrons are micro-bunched in the periodic potential and groups of electrons become **point-like radiation sources**





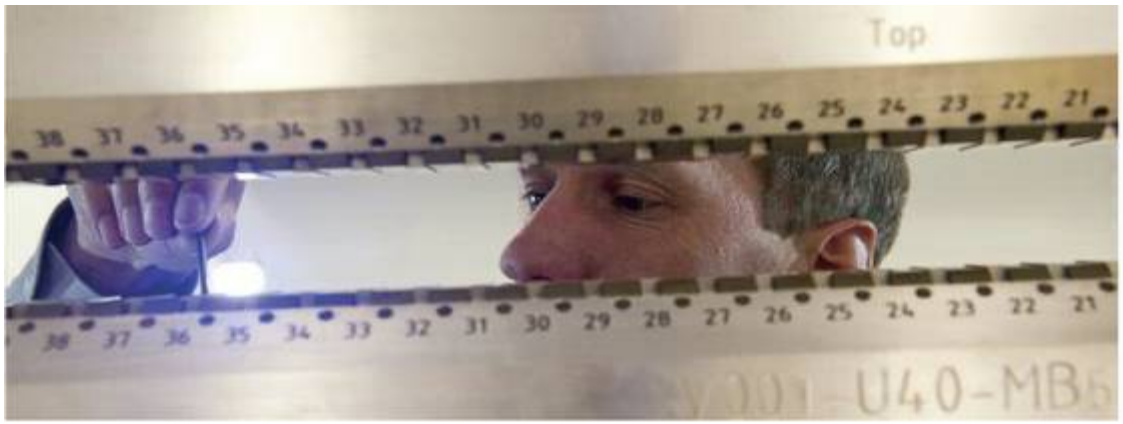
- The intensity of the light wave becomes p^{p}, N being the number of electrons
- The FEL photon pulse energy is growing exponentially

European XFEL

Undulator production finished April 2015

	SASE1/2	SASE3
λ_0 [mm]	40	68
Operational Gap Range [mm]	10-20	10-25
K-Range	3.9–1.65	9.0-4
Radiation Wavelength Range [nm]		
@ 17.5 GeV	0.147-0.040	1.22-0.27
@ 14.0 GeV	0.230-0.063	1.90-0.42
@ 8.5 GeV	0.625-0.171	5.17-1.15
# of Segments	35	21
System Length [m]	213.5	128.1

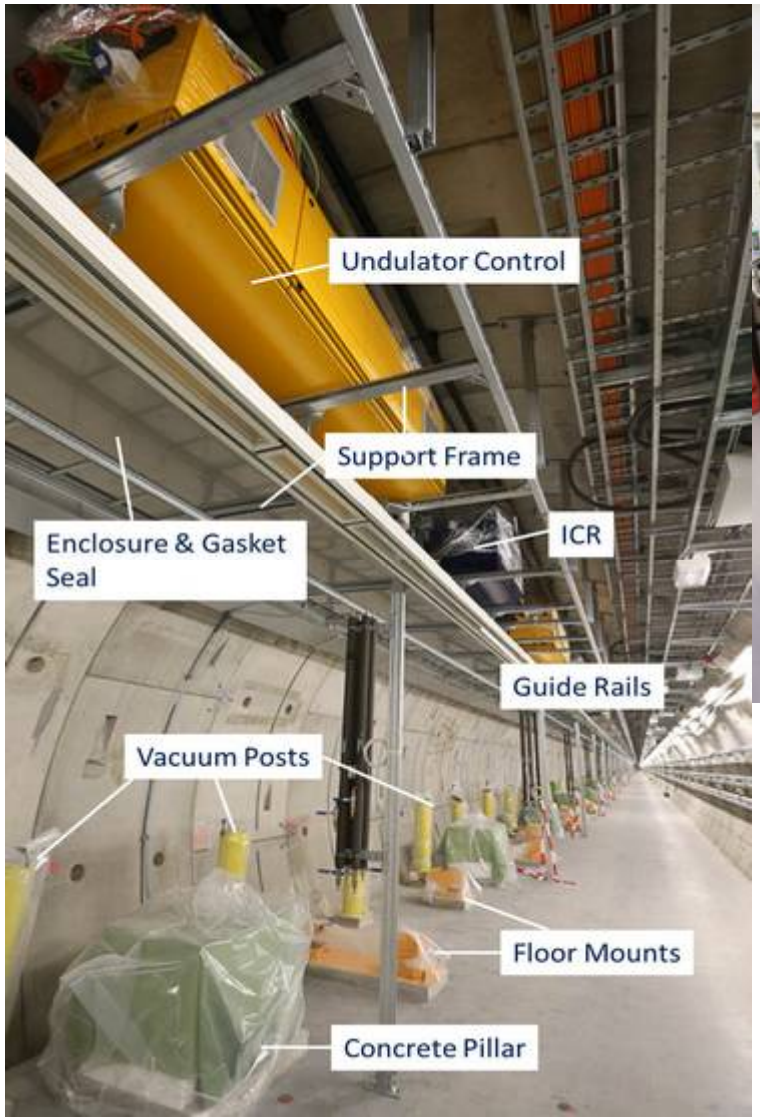
Courtesy J. Pflüger

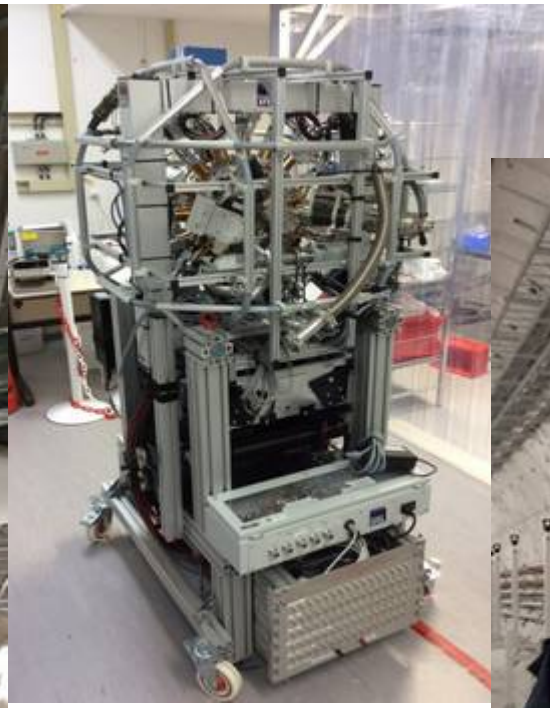


Main components of the accelerator - Experiments

European XFEL

X-ray Beam Transport and Diagnostics



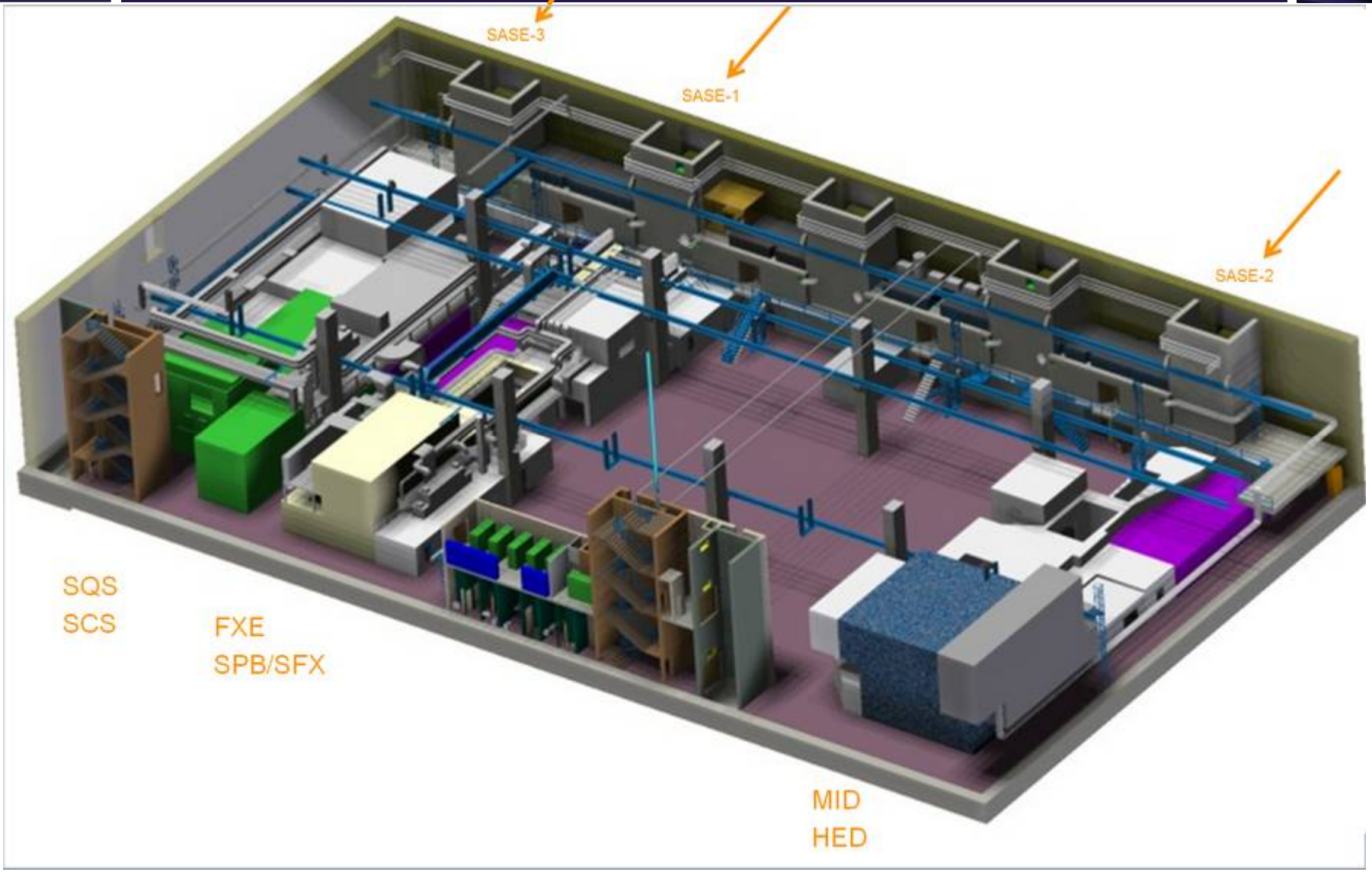


SASE1

Tunnel

European XFEL

Experimental hall



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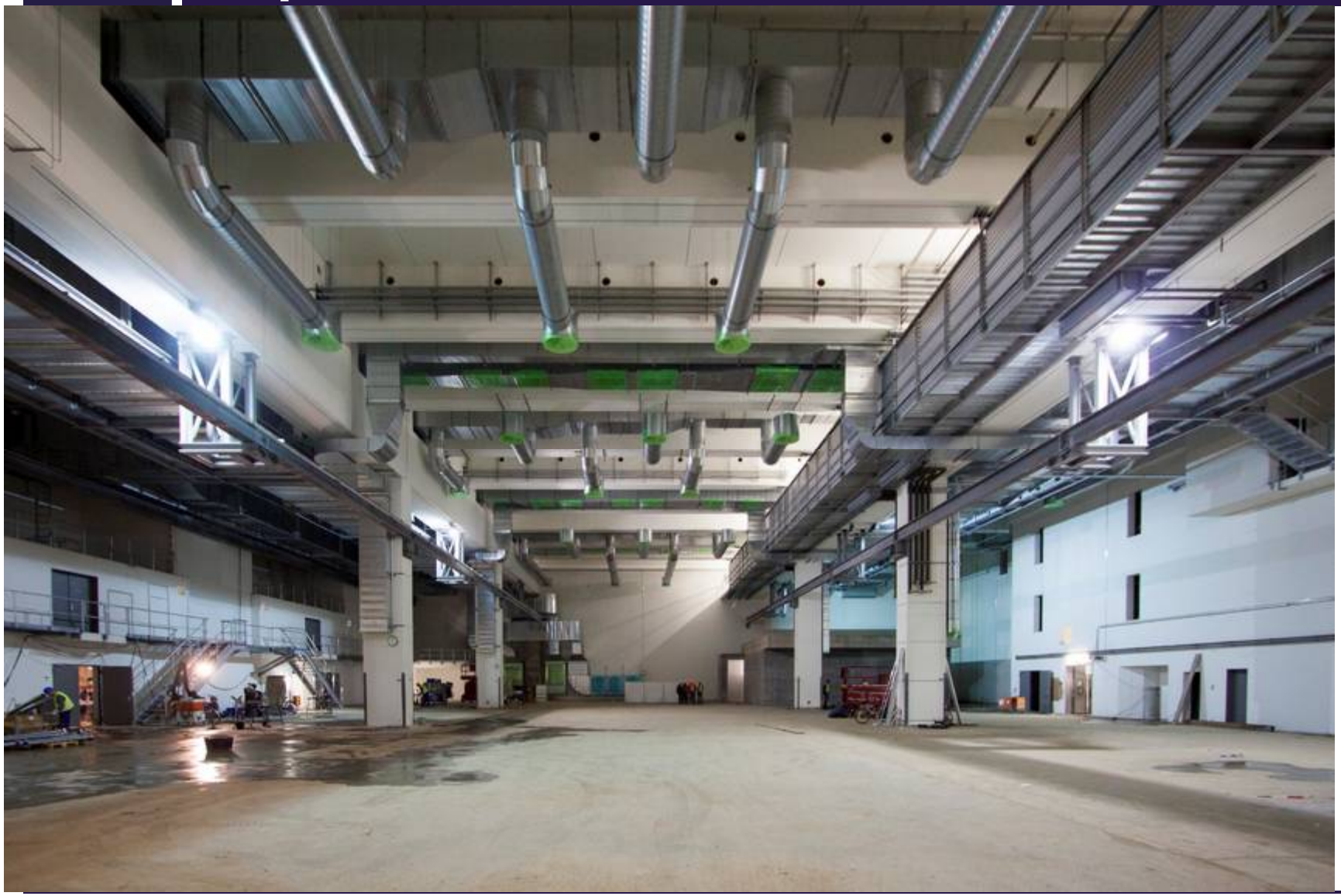
Experiment Hall, October 2014



European XFEL

Construction of HED-Enclosure 11.2.2015

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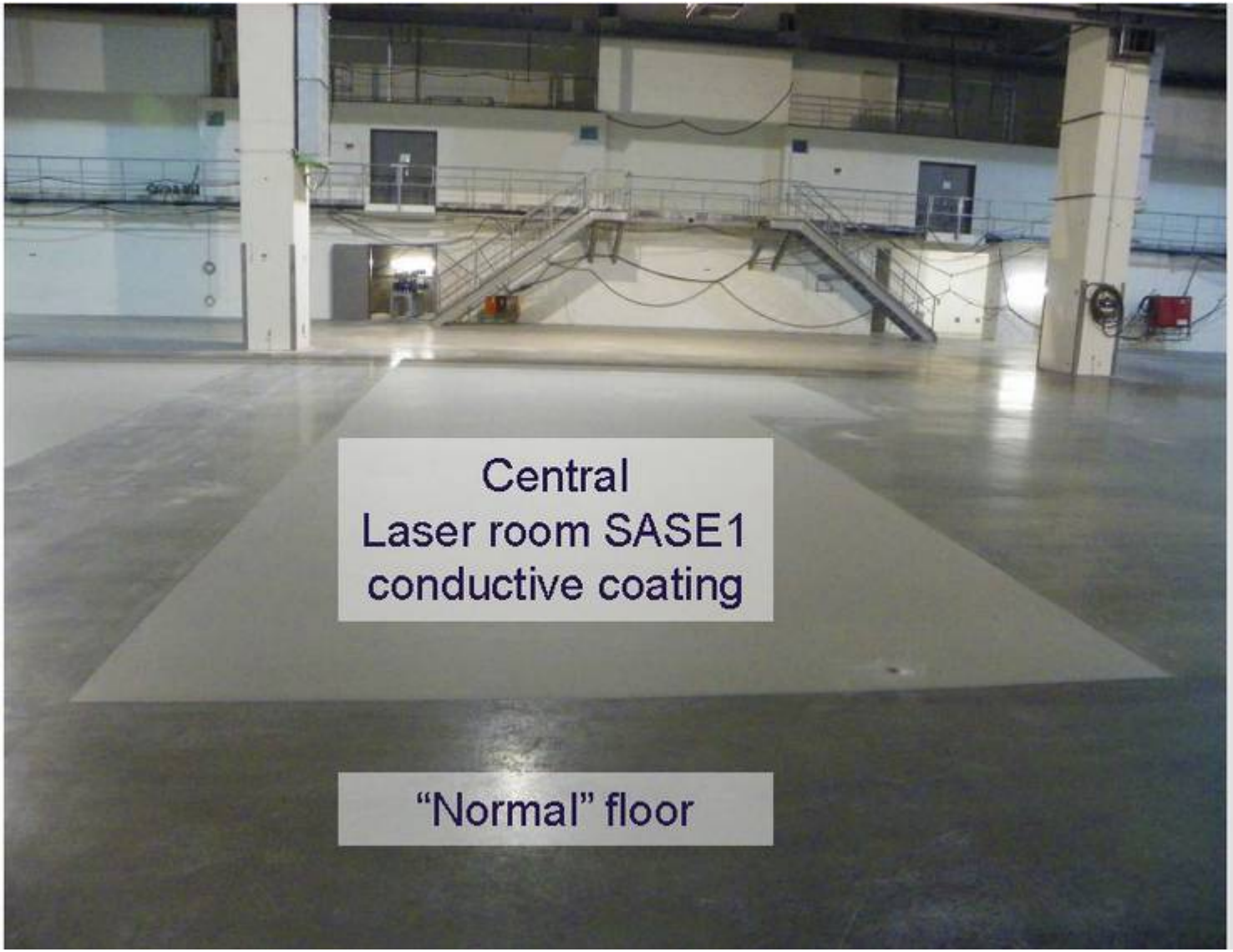
Floor coatings



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Floor coating SASE1

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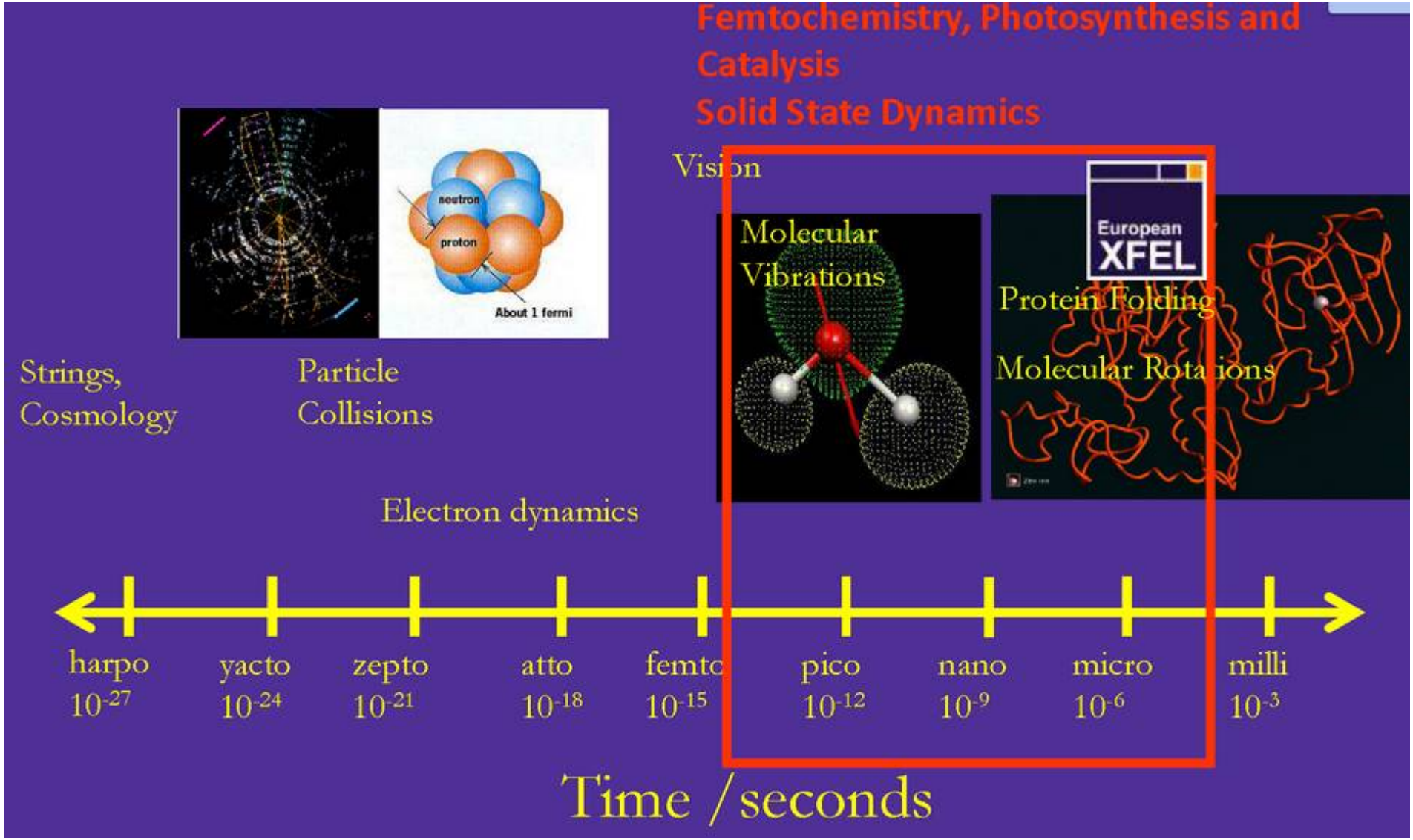
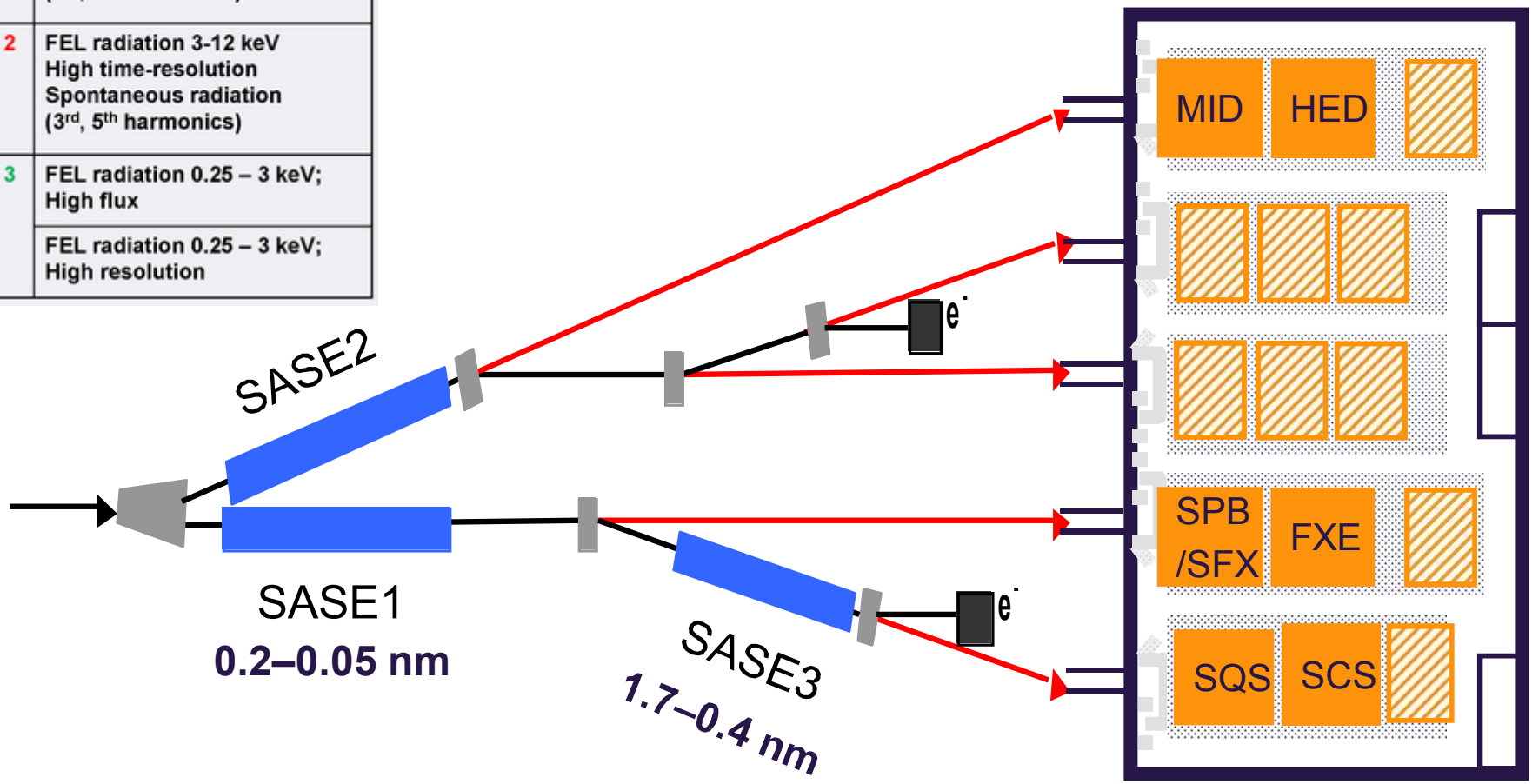
Fundamental Timescales



Schematic distribution of the instruments

Source	Photon beam line characeristics
SASE 1	FEL radiation ~12 keV High coherence Spontaneous radiation (3rd, 5th harmonics)
SASE 2	FEL radiation 3-12 keV High time-resolution Spontaneous radiation (3rd, 5th harmonics)
SASE 3	FEL radiation 0.25 – 3 keV; High flux
	FEL radiation 0.25 – 3 keV; High resolution



European XFEL

Instruments

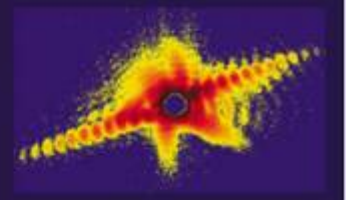
Hard X-rays

SPB: Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules

Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.

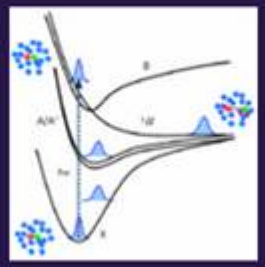
MID: Materials Imaging & Dynamics

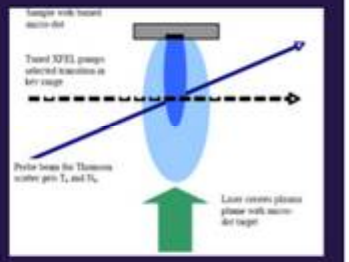
Structure determination of nano-devices and dynamics at the nanoscale.



FXE: Femtosecond X-ray Experiments

Time-resolved investigations of the dynamics of solids, liquids, gases





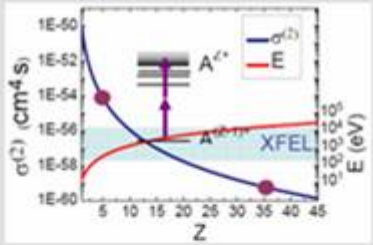
HED: High Energy Density Matter

Investigation of matter under extreme conditions using hard X-ray FEL radiation, e.g. probing dense plasmas

Soft x-rays

SQS: Small Quantum Systems

Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

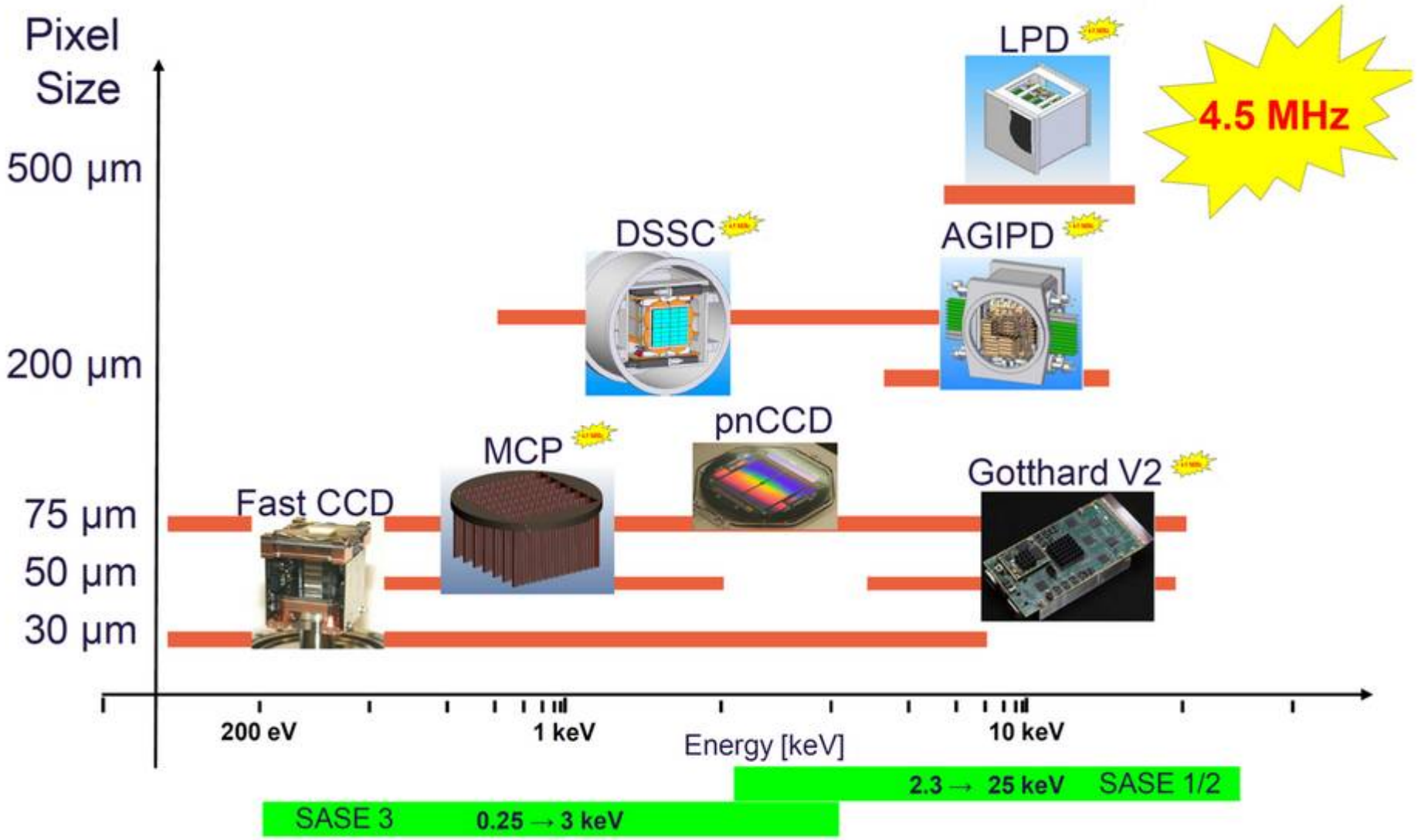


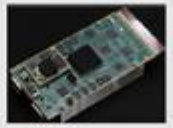
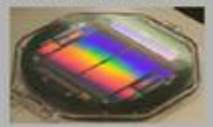
SCS: Soft x-ray Coherent Scattering/Spectroscopy

Electronic and real structure, dynamics of nano-systems and of non-reproducible biological objects

European XFEL

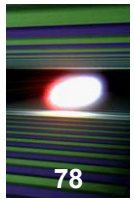
Detectors for Day-1 of Operation



SASE 1 / High E	Single Particles, Clusters and Biomolecules (SPB)	AGIPD 	Gotthard V2 	Fast CCD 	
SASE 1 / High E	Materials Imaging & Dynamics (MID)	AGIPD 	Gotthard V2 		
SASE 2 / High E	Femto Second X-ray Experiments (FXE)	LPD 	Gotthard V2 	Gotthard V1 	
SASE 2 / High E	High Energy Density Matter (HED)		Gotthard V2 		
SASE 3 / Low E	Small Quantum Systems (SQS)	DSSC 	Fast CCD 	MCP 	
SASE 3 / Low E	Spectroscopy and Coherent Scattering (SCS)	DSSC 	Fast CCD 	MCP 	Small pnCCD 

European XFEL

Present planning (T. Haas)



- SASE1
  - Hutch Construction: Apr - Sep '15
  - Infrastructure: Oct '15 - Mar '16
    - All Hutches and Infrastructure done (Instrument Installation possible): March 2016
      - 9 months for Instrument Installation
- SASE3
  - Hutch Construction: Jul - Oct '15
  - Infrastructure: Nov '15 - Apr '16
    - All Hutches and Infrastructure done (Instrument Installation possible): April 2016
      - 9 months for Instrument Installation
- SASE2
  - Hutch Construction: Oct '15 - Jan '16
  - Infrastructure: Feb - Jun '16
    - All Hutches and Infrastructure done (Instrument Installation possible): Jun 2016
      - 10 months for Instrument Installation

European XFEL

XHQ building, Jan. 2015

European XFEL

XHQ building, moving in late spring 2016

European XFEL

Guest house, canteen

No investment funds in the baseline budget!

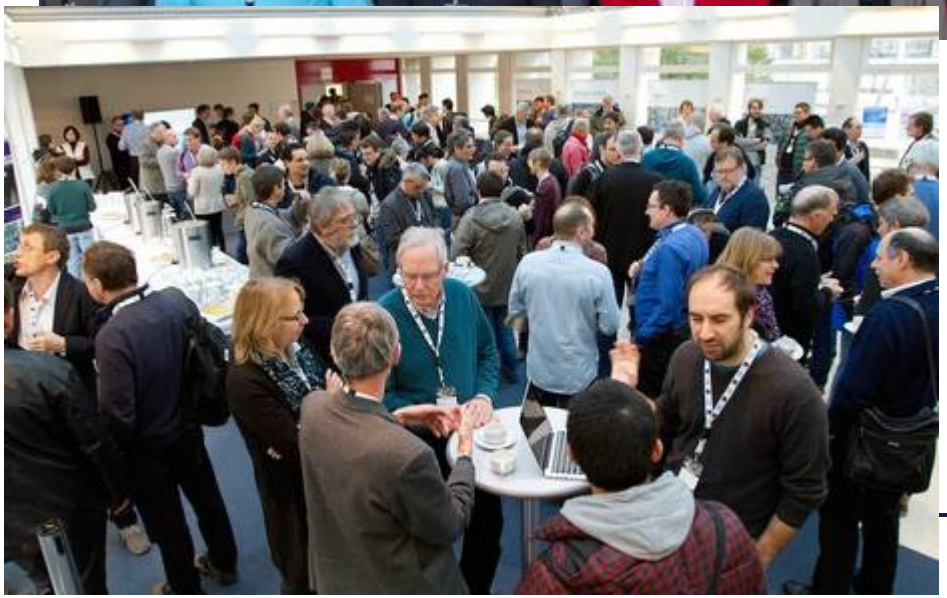
European XFEL

From the project general schedule

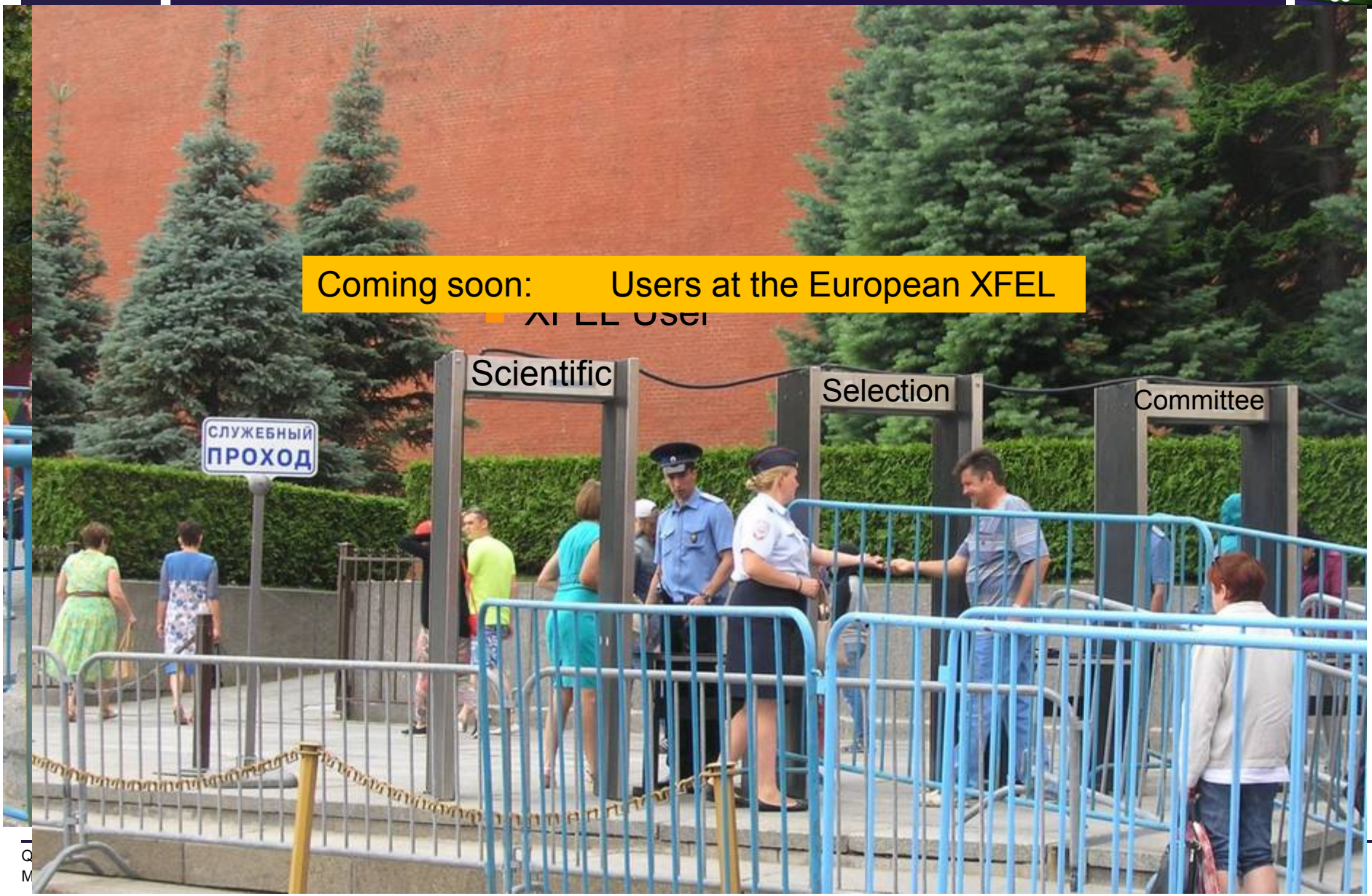
WHEN	MILESTONE
30 June 2015	Injector Tunnel closed
31 January 2016 => 31 March 2016	SASE1 experimental area ready for instrument (FXE, SPB/SFX) installation
30 June 2016	Linac tunnel closed
31 December 2016	First SASE1 lasing possible
30 April 2017	SASE1 instruments begin operation

European XFEL

XFEL.EU / DESY Users' Meeting 2015




Coming soon: Users at the European XFEL


Coming soon: Users at the European XFEL
Scientific
Selection
Committee
СЛУЖЕБНЫЙ
ПРОХОД

Acknowledgments/sources

www.xfel.eu

talks at user meetings Jan/April 2015

A. Altarelli, H. Weise, F. Brinker, A. Schwarz, T. Haas,

W. Gawelda, A. Scherz, M. Meyer, T. Tschentscher,

A. Mancuso, C. Bressler, H. Sinn, M. Hüning

H. Weise www.desy.de/~weise


European XFEL
Thank you for your attention!