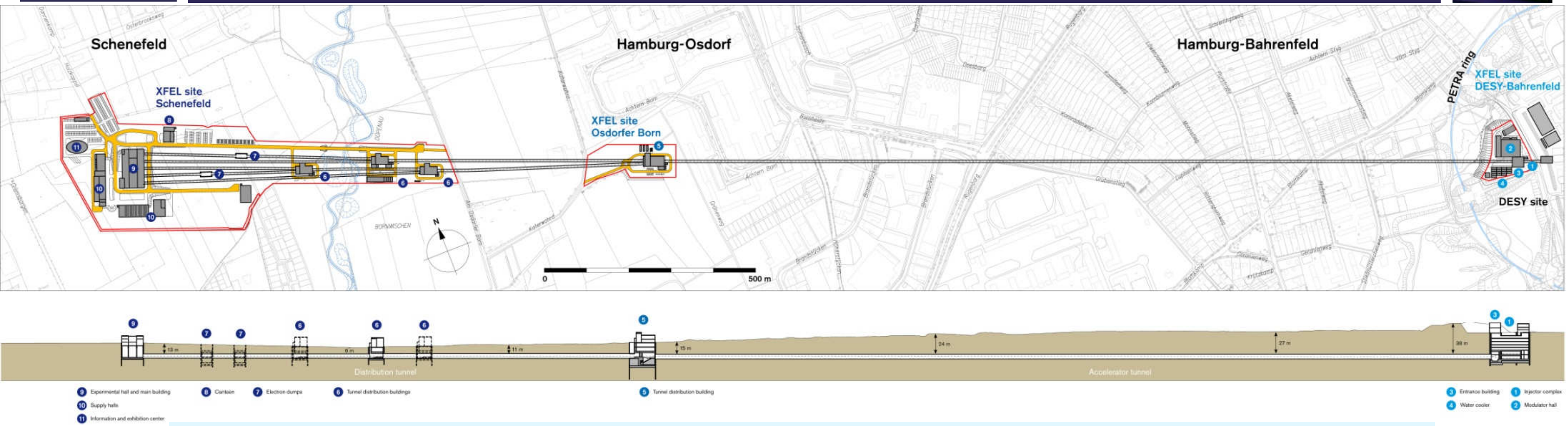
European XFEL in-kind contributions: a look into the main features of the designed vacuum systems

Antonio Bonucci– IKC Supply Chain Manager
European XFEL
Albert-Einstein-Ring 19
22761 Hamburg
Germany

Overview

- Short overview of the European XFEL project
- Vacuum Technology in IKC in the construction phase
- UHV Guidelines for X-Ray Beam Transport Systems
- Conclusions

Main facts about the project

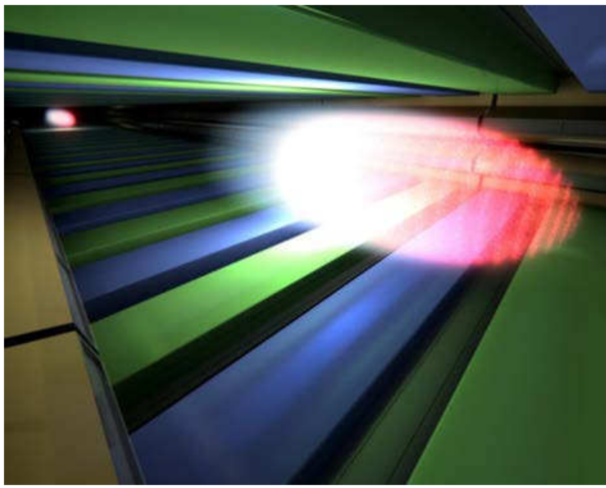


The European XFEL Facility in Hamburg is an applied research facility

- Generation of X-ray flashes: 27 000/s
- Superconducting linear accelerator for electrons (energy level 17.5 GeV)
- 3.4 km long machine in 5.8 km underground tunnels
- 3 sites above ground and 5 experimental stations (3 in the start-up)

- **Construction** :
- Cost 1.15 B€ (2005) or 1.43 B€ (2013)
- 12 countries participate in the construction through 21 institutes
- 48 Work Packages
- 76 in-kind contributions
- Lifetime 20 years 2016-2036

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

Opportunities: biology, medicine, pharmacology

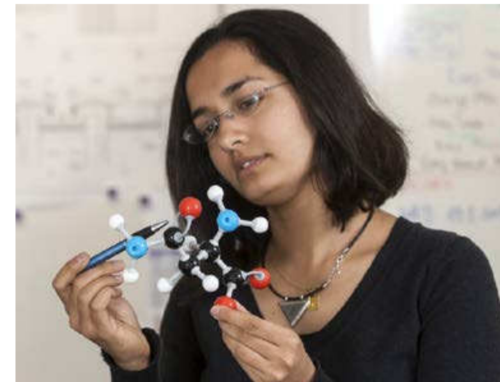
- Molecular movies reveal biochemical processes
  - Causes of protein misfolding → treatments for Alzheimer's, BSE, etc.
  - Understanding enzymatic action in greater detail → better medicines, fewer side effects
  - Viewing mechanisms of infection

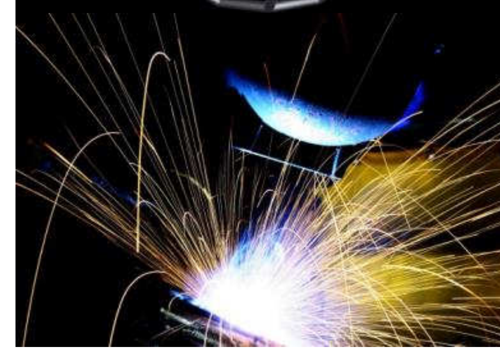
- High intensity X-rays show structures in greater detail
  - Searching for weaknesses in viral and bacterial outer coats

Opportunities: chemistry and materials science

- Atomic-level imaging can uncover action of catalysts
  - Better catalytic converters lessen impact of emissions
  - Less toxic production processes

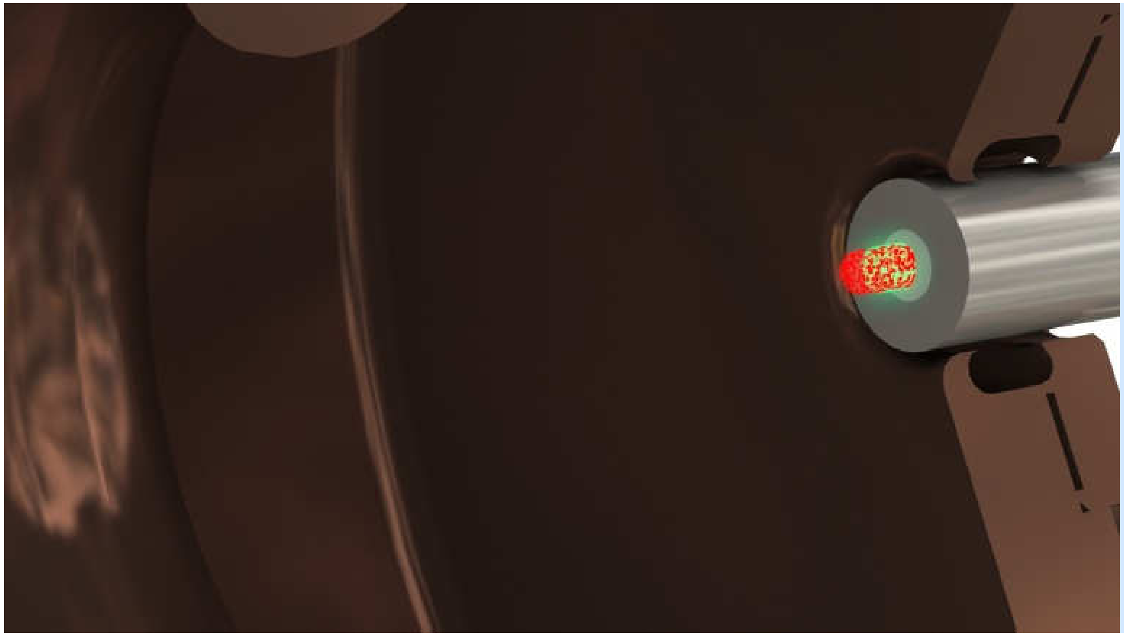
- Studying structure and properties of materials as never before
  - How properties (e.g. durability, conductivity, magnetism) manifest
  - Reducing atoms needed to store digital information → ultrahigh-capacity hard drives





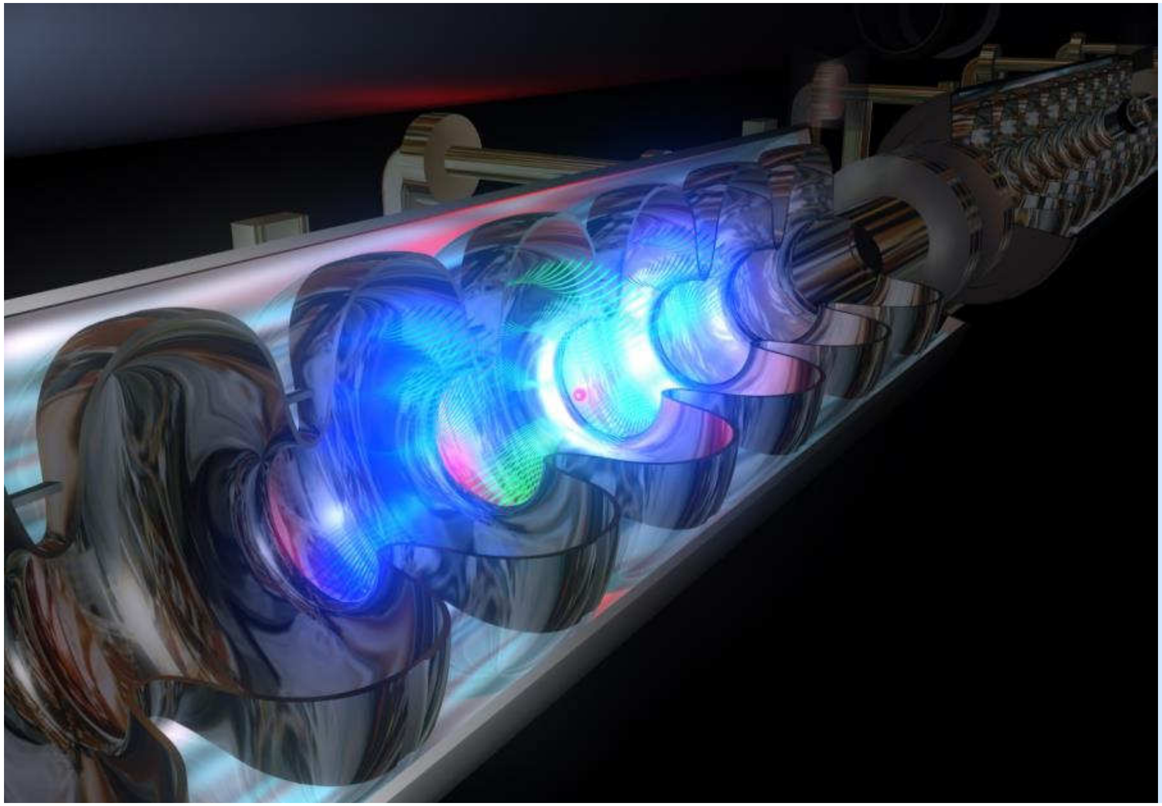
How it works: a closer look at the facility

Injector: creating bunches of electrons



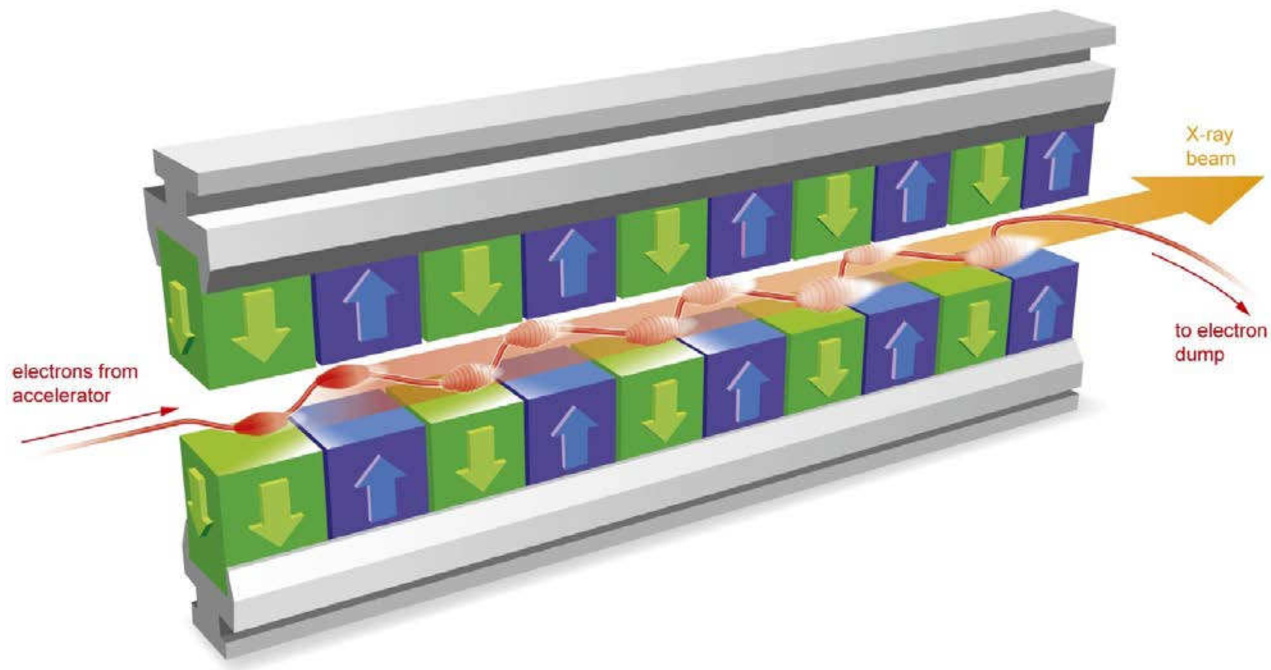
- Optical laser strikes Cs_2Te surface, releasing a cloud of electrons
- Electrons move into a magnetic field, shaping into a bunch
- Small accelerator module “fires” bunch into the main electron accelerator

Accelerator: electrons at close to light speed



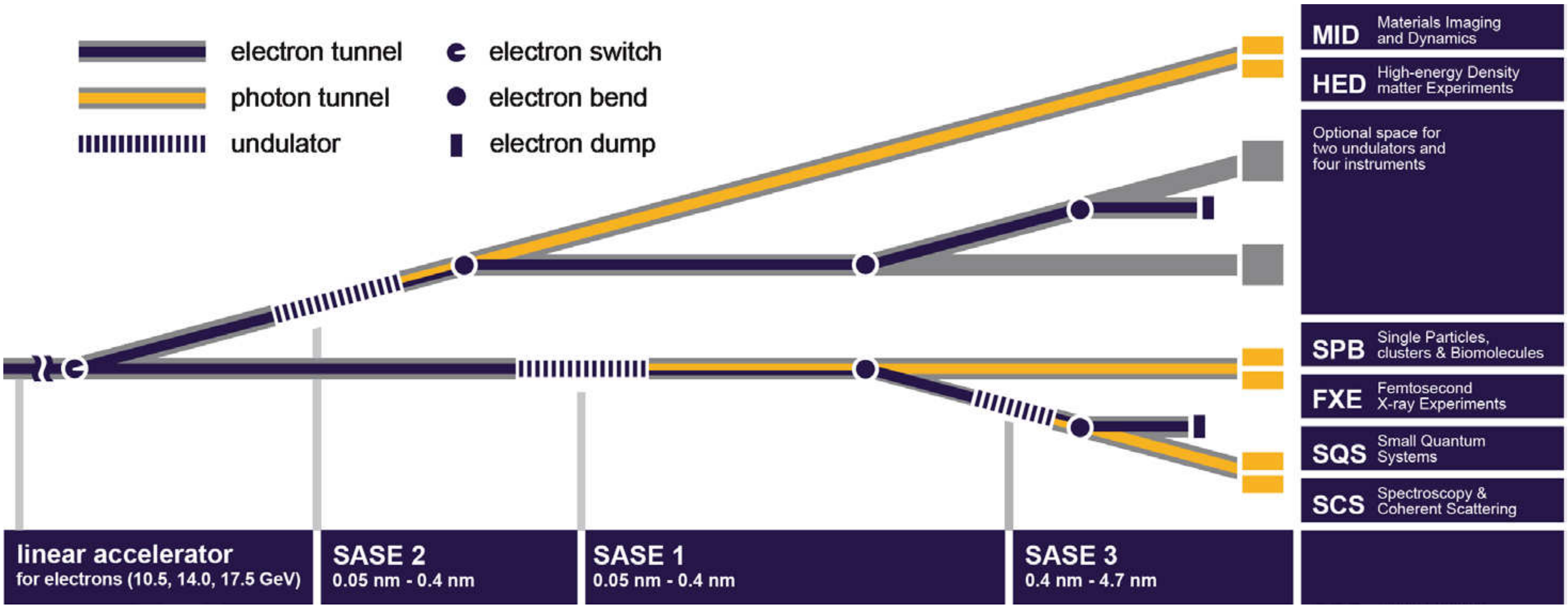
- 100 accelerator modules over 2 km bring the electron bunch to near light speed and high energies
- Superconducting niobium cavities powered by intense radio frequency accelerate electrons

SASE 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

Beamline layout & experiment stations



Scientific instruments

Hard X-rays

SPB: Single Particles, Clusters, and Biomolecules

- Will determine the structure of single particles, such as atomic clusters, viruses, and biomolecules

MID: Materials Imaging and Dynamics

- Will be able to image and analyze nano-sized devices and materials used in engineering

FXE: Femtosecond X-Ray Experiments

- Will investigate chemical reactions at the atomic scale in short time scales—molecular movies

HED: High Energy Density Physics

- Will look into some of the most extreme states of matter in the universe, such as the conditions at the center of planets

Soft X-rays

SQS: Small Quantum Systems

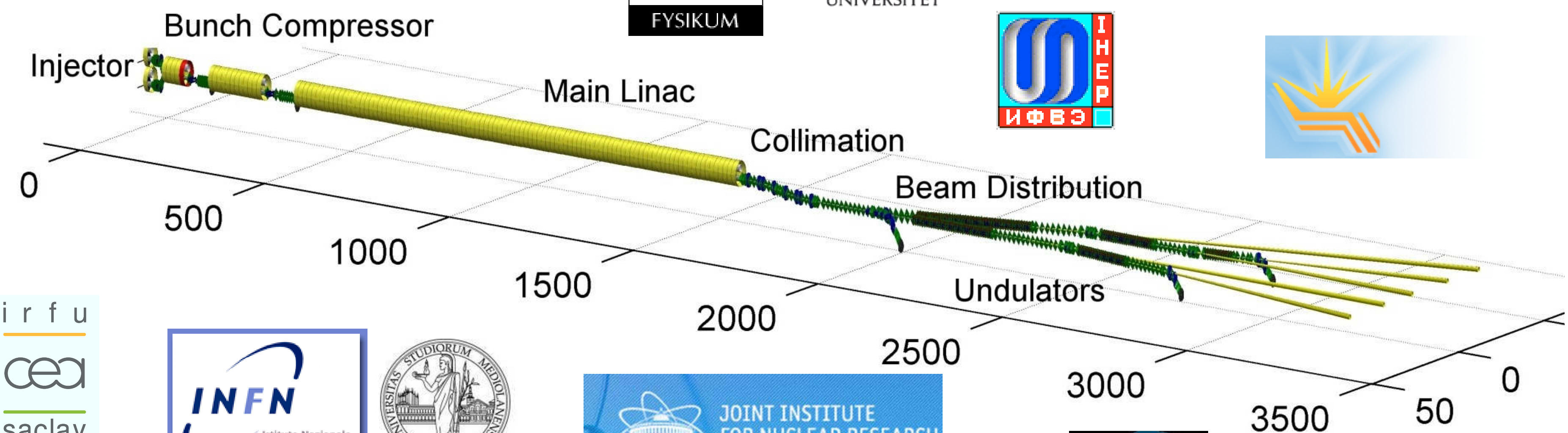
- Will examine the quantum mechanical properties of atoms and molecules.

SCS: Spectroscopy and Coherent Scattering

- Will determine the structure and properties of large, complex molecules and nano-sized structures.

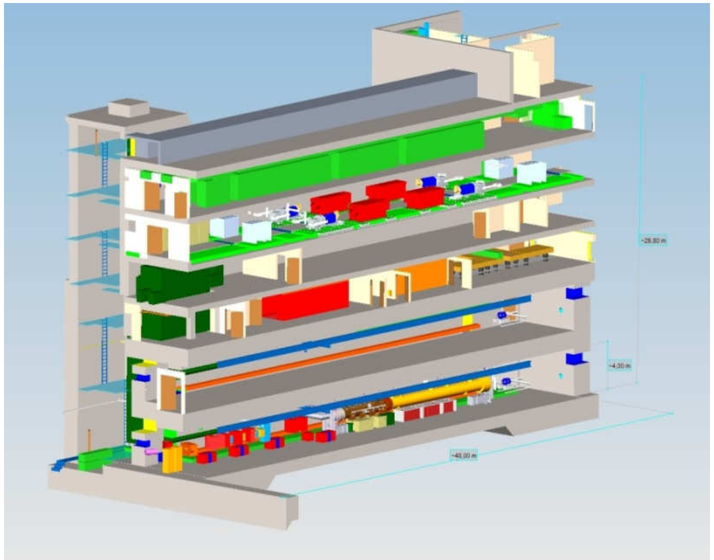
Institutes contributing in-kind to the construction

DESY
KTH VETENSKAP OCH KONST
Stockholm University
UNIVERSITET STOCKHOLMS FYSIKUM
UPPSALA UNIVERSITET
ИЯИ
IHEP ИФВЭ



irfu cea saclay
INFN Istituto Nazionale di Fisica Nucleare
UNIVERSITAS STUDIORUM MEDIOLANENSIS
JOINT INSTITUTE FOR NUCLEAR RESEARCH
ifj
PAUL SCHERRER INSTITUT PSI
cnrs In2p3
ncbj
Wrocław University of Technology
MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
UNIVERSIDAD POLITÉCNICA MADRID
DTU

Underground Injector building

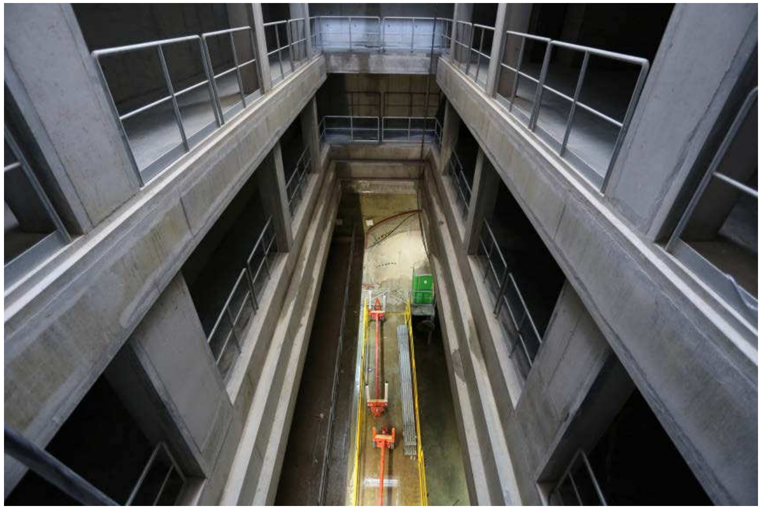


Underground injector building: 7 levels, 38m deep

Oct. 2009

RF power components

Electron gun



Main shaft

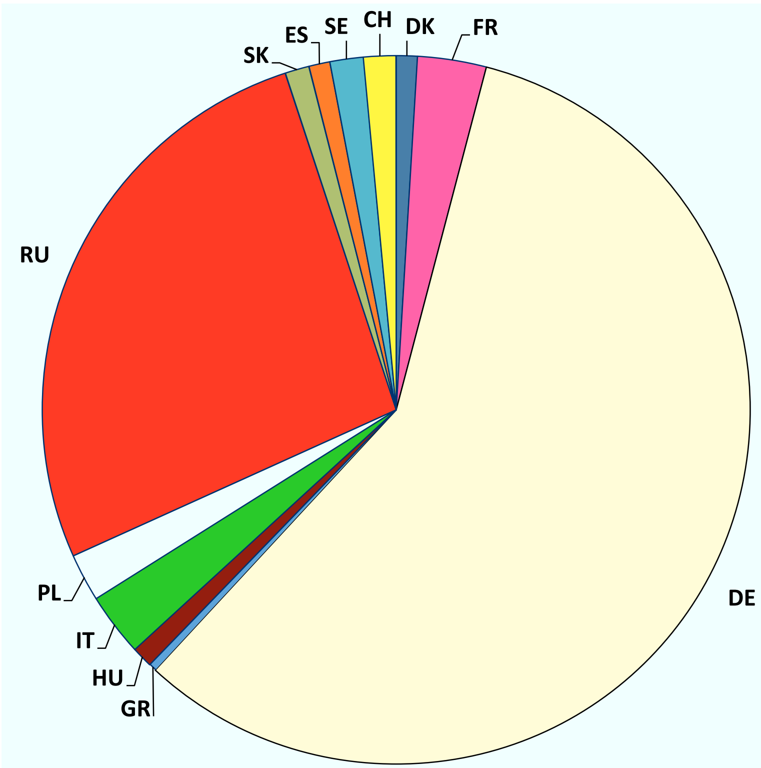
Main tunnel is 2 km long

Floor laying

Utilities installed in accelerator tunnel

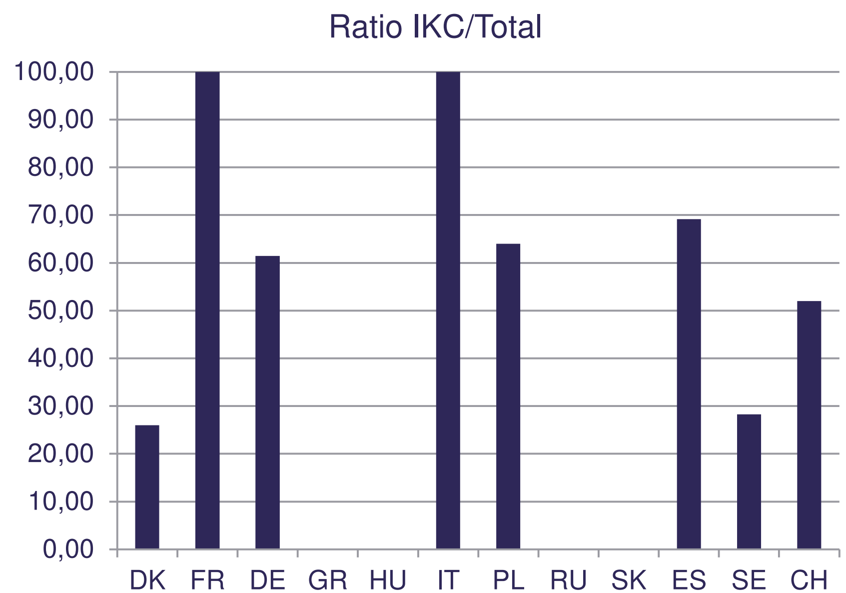
Vehicle for cryomodule transport

12 countries contribute to the European XFEL Facility



Distribution of total contributions

Each country contributes either in cash, in-kind, or both to the construction phase



Overview of in-kind contributions end 2014

- 9 Countries
- 21 Institutes
- 78 IKCs
- 610 Milestones
- 560 M€ (2005)

Efforts by IKC Office →

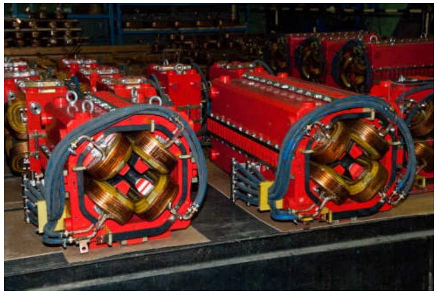
- Prepare agreements
- Implement changes
- Validate milestones
- Follow-up and control
- Verify achievements

Status end 2014

- 67 IKCs allocated
- 216 Milestones completed
- 10 IKCs completed
- Project delay, but already many components delivered

Main components delivered

- Super-conducting cavities: 540/800
- Cryostats: 85/100
- Warm magnets: 715/715
- Cold magnets: 100/100



Vacuum Technology in IKC

Vacuum Technology is a fundamental brick all over the facility.

The beam vacuum system of this facility contains sections operated at room temperature as well as at 2 K in the areas of the superconducting accelerating structures. Accordingly, the requirements, technical challenges and solutions for the various sections are quite different.

The Vacuum Technology in the In-Kind contribution are treated in the following work packages:

- **WP08/ RU18 "Cold Vacuum", collaboration with DESY (Deutsches Elektronen-Synchrotron) and BINP (Budker Institute of Nuclear Physics) Novosibirsk**

Superconducting Linear Accelerator

- **WP19/RU19 " Warm Vacuum", collaboration with DESY and BINP Novosibirsk**

Injector and Bunch Compressors, Collimation and Beam distribution, Undulators, Transport Beam Lines and Beam Dumps

- **Scientific Instruments with different requirements**

DESY Technical Specification and guidelines for UHV Components are available at the address
http://edmsdirect.desy.de/edmsdirect/item.jsp?edmsid=D00000001425601,D,1,2

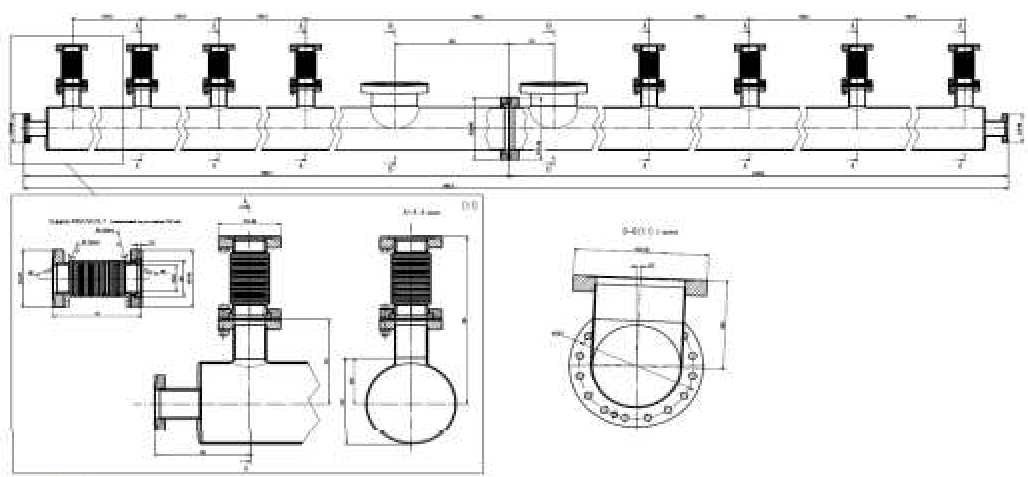
WP08/RU18: deliverables

Tasks DE08 (DESY):

- Accelerator modules
  - Cleaning of 808 inter-cavity bellows
  - Cleaning of 101 coupler pump lines with 808 coupler bellows
  - Purchase and cleaning of 202 manual gate valves
  - Purchase, cleaning and commissioning of 101 titanium sublimation pumps and 101 sputter ion pumps
  - Coupler vacuum
- Cryogenic boxes
  - Design, manufacture and cleaning of the vacuum piping for the cryogenic boxes
  - Purchase and cleaning manual gate valves

Tasks RU18 (BINP):

- Production of 848 cavity bellows
- Production of 848 coupler bellows
- Production of 106 pump lines
- Shipment to Saclay for integration (FR02 and FR03)



Cavity bellows prototypes are validated

Specification:

- Cu coating 15 ± 5 μm
- Heat treatment for quality check of Cu coating at 300° C
- He leak rate < 10^{-10} mbar l/s
- vacuum firing according to CERN procedure in clean furnace with p < 10-5 mbar l/s at 950° C
- The bellows need to be particle free. The particle cleaning will be done at DESY. Any change in the design and manufacturing of the vacuum components have to be done in a way to allow particle cleaning with wet processes (US bath, rinsing with ultra pure water) and drying with warm gas (≤ 100° C) before installation.

WP19/RU19: deliverables

Tasks DE19 (DESY):

- Gun + vacuum system before first module
- Injector except BC0 chicane (RU19) and laser heater (SE03)
- Injector dump vacuum
- BC1 and BC2 except chicane (RU19) ca. 150 m, average pump distance. 3-5 m
- BC1 and BC2 dump vacuum
- Temporary beamline
- Collimation except main collimators (RU19), ca. 215 m , a.p.d ca. 6 m
- Undulator vacuum chambers (SASE1, SASE2, SASE3) (92 chamber)
- Beam Distribution
- Main dumps
- WP19 does not supply diagnostic and special diagnostic components (WP17 and WP18) but WP19 has to take care of quality for all WP19 and non-WP19 vacuum components
- Purchase, cleaning and commissioning of sputter ion pumps

Tasks RU19 (BINP):

Production of:

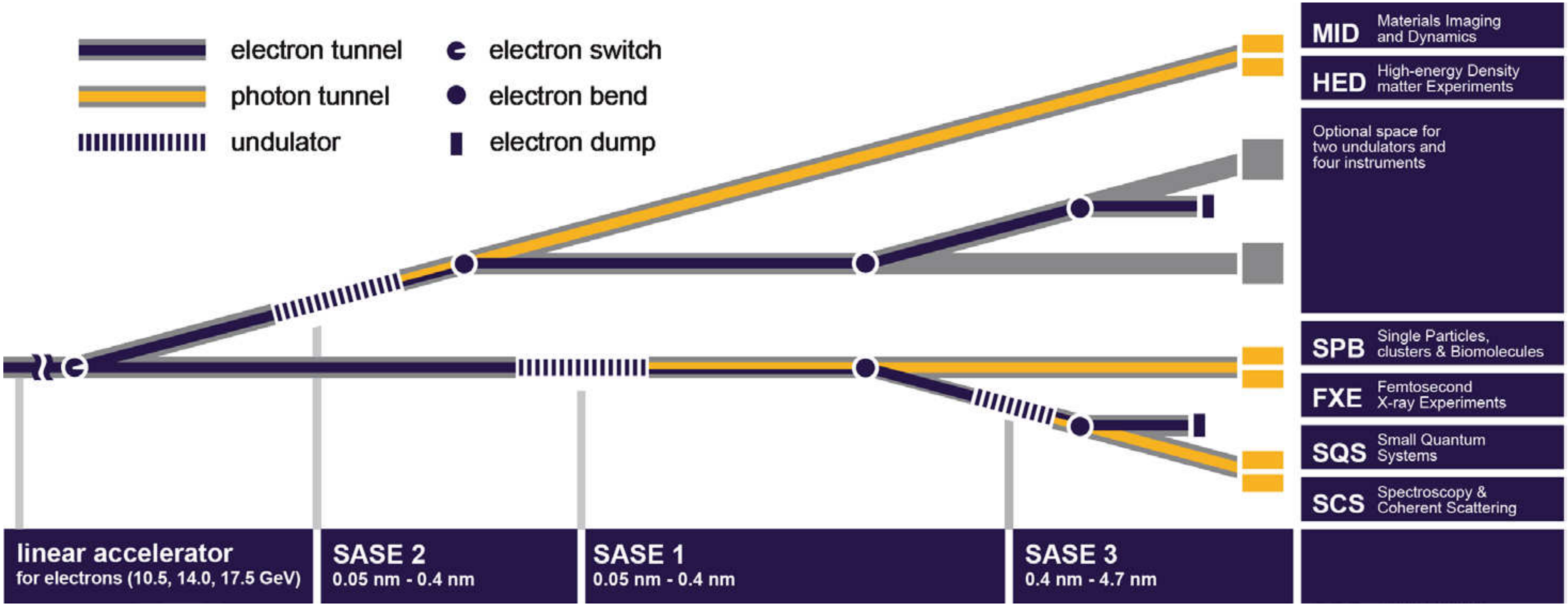
- Chicane sections BC1, BC2: 2 units
- Chicane section BC0: 1 unit
- Collimators: 5 units
- Intersections of Undulators beam lines: 100 units
- Vacuum system for beam distribution: 1620 meters
- Temporary beam lines tubes: 200 m
- Delivery to DESY for integration (DE19)

Compensator

BC dipole chamber

Vacuum system for beam distribution: For pressure simulations an outgassing rate of Q = $5 \cdot 10^{-11}$ mbar l/s/cm2 should be assumed. The aim is an average pressure of p = $2 \cdot 10^{-8}$ mbar.

Experimental hutches



FXE experiment (Prof. Christian Bressler) DK01
In UHV components

P<1e-7 about 1e-8/1e-9

SQS experimnt (Dr. Michael Mayer) SE10/SE11

P~1e-10 mbar

UHV Guidelines for X-Ray Beam Transport Systems

The guidelines are available on http://www.xfel.eu/project/organization/work_packages/wp_73
With detailed information about:

- **UHV-compatible design (Flanges , Designs)** … for instance use flanges knife-edge" type (according to ISO 3669-2:2007) that are sealed by means of a flat circular gasket made of oxygen-free high conductivity (OFHC) copper. The gasket cannot be reused.
- **UHV-compatible materials**

Type	Compatible	Incompatible
Pure metal	Aluminium Beryllium Copper Indium Molybdenum Tantalum Titanium Tungsten	(e.g. Cadmium, Lead, Zinc)
Stainless steel	Preferred types: 304L and 316L for pipes, 316LN ESR for flanges	Steel containing incompatible materials (e.g. 303, 303S, 303Se)
Alloy	Appropriate aluminum alloys Beryllium-copper DENSIMET® GLIDKOP® INCONEL® 600, 718 Tin-bronze	Inappropriate aluminium alloys (e.g. alloys containing lead) Zinc (e.g. brass)
Other	Aluminium ceramics Boron carbide (B_4C) Diamond, Sapphire Macor®, PEEK, PI (Kapton®, Vespel®)	Organic materials (with a few exceptions) Glue

UHV Guidelines for X-Ray Beam Transport Systems

- **Electrical connections inside vacuum (Kapton®- or ceramic-insulated)**
- **Feedthroughs**:
  - Electrical (Feedthroughs used for electrical connections into the vacuum system must be of the ceramic-to-metal type. No glass-to-metal feedthroughs are permitted.)
  - Mechanical (Bellow-type mechanical feedthroughs or magnetically coupled feedthroughs have to be used to impart a rotational or linear movement to the vacuum. O-ring-sealed feedthroughs are not permitted.)
- **Guidelines for UHV systems** (Manufacturing and assembly ,Cleaning of large items and small parts, handling, Packing)

For instance for large parts:

- Chemical mechanical precleaning (based on HNO_3)
- Rinsing with water (resistivity ≥ 1 MΩcm-1 at 25° C)
- Depending on the dimensions of the item to be cleaned, do one of the following:
  - Long pipe sections: Anodical cleaning (based on H_2SO_4 and H_3PO_4)
  - Vacuum chambers, vessels or buffers: Pickling (based on HF and HNO_3)
- Rinsing with water (resistivity ≥ 1 MΩcm-1 at 25° C)
- Chemical passivation of the surface (based on HNO_3)
- Rinsing with water (resistivity ≥1 MΩcm-1 at 25° C)
- Final treatment (for particle-free cleaning, continue with Section 4.1, "Cleaning and assembly")
  - Rinsing with 80° C DI water (resistivity ≥ 15 MΩcm-1 at 25° C)
  - Drying with Nitrogen (quality 5.0 or better)

UHV Guidelines for X-Ray Beam Transport Systems

- **Particle-free UHV systems**

You must verify the absence of particles in the cleaned components inside a cleanroom with ISO Class 5 or better. Therefore, clean the components with particle-free ionized nitrogen. After 5 minutes of using a gas throughput of 28 l/min, a maximum of 10 particles per minute with a size ≥ 0.3 µm should be detected.

- **Vacuum tests:**
  - **Leak tests:**
    - Integral leak rate acceptance criterion Make sure that the integral leak rate (sum of all leaks) is ≤ $1\cdot10^{-10}$ mbar·l·sec^{-1}.
  - **Residual gas analysis**
    - **Acceptance criteria for unbaked vacuum systems**
      - The mass 18 peak of the leak-free system reaches a pressure below 5·10-8 mbar.
      - After 15 hours of pumping the RGA spectra are recorded:
      - All mass peaks between mass 18 and 44 have to be 100 times lower than the mass 18 peak, except masses 28, 32, and 44.
      - All mass peaks from mass 45 have to be 1000 times lower than the mass 18 peak.
    - **Acceptance criteria for baked vacuum systems**
      - Leak-free system reaches a total pressure below 10^{-7} mbar.
      - Sum of the partial pressures of masses from mass 45 on to at least mass 100 is less than 10^{-3} of the total pressure.
      - For documentation, a mass spectrum (at least masses 1–100 amu, resolution 1·10-14 mbar)) of each component is needed, as well as a reference spectrum of the applied pumping system itself.
      - The integral specific desorption rate for baked components should be ≤ 5–10^{-12} mbar·l·sec^{-1}·cm^{-2}.

Conclusions

- Vacuum technology is one of the most important component of XFEL project
- In Kind Contribution has been allocated both for the warm and for the cold vacuum
- UHV and Particle-free requirements have been extensively defined with detailed differences in the different areas of the facilities.

Acknowledgements:

Budker Institute of Nuclear Physics, Novosibirsk, **Dr. Alexander Krasnov,**

Prof. Vadim Anashin

Deutsches Elektronen-Synchrotron, Hamburg, **Dr. Lutz Lilje**

Dr. Sven Lederer

Dr. Martin Dommach and all the staff of European XFEL