

## 3 General layout of the XFEL Facility

### 3.1 Introduction

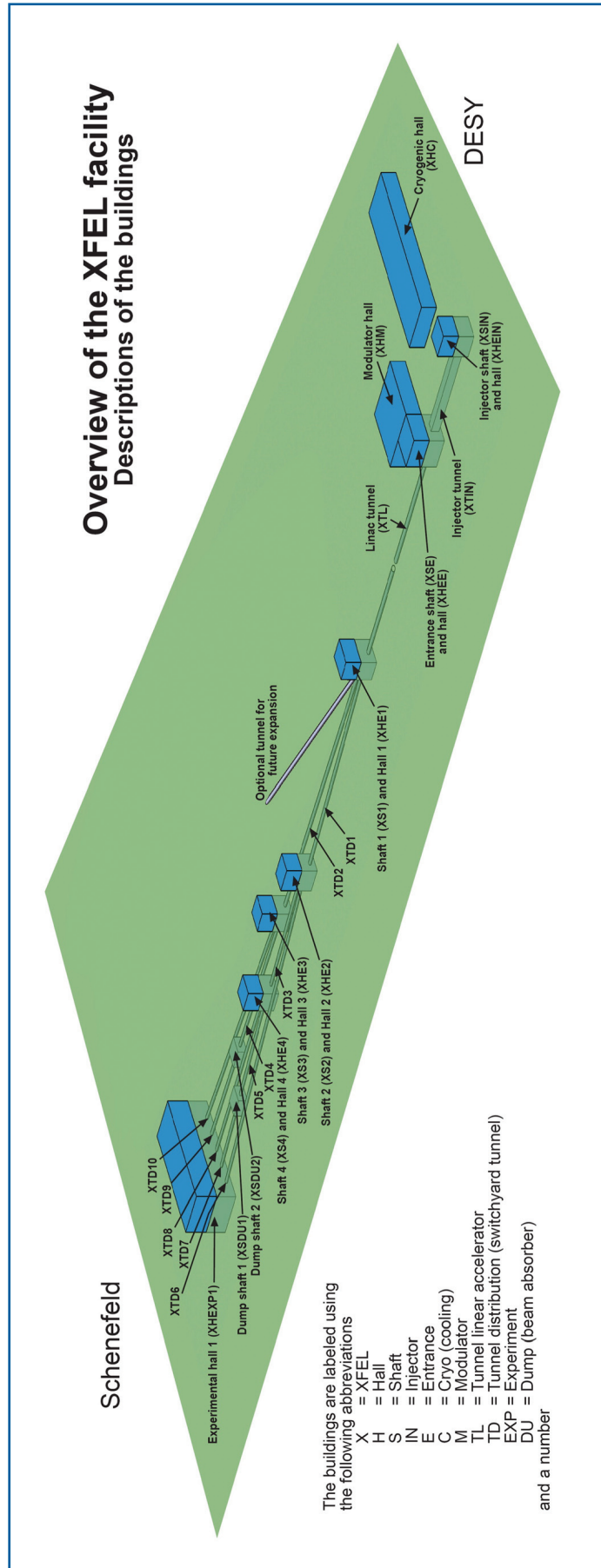
The present chapter provides an overview of the whole European X-Ray Free-Electron Laser (XFEL) Facility layout, enumerating its main components and describing their position and arrangement on the site. Its purpose is to guide the reader through the much more detailed description of the individual components that follows in the subsequent chapters. For the purpose of this overview, the main components of the facility are the:

- injector;
- linear accelerator (linac);
- beam distribution system;
- undulators;
- photon beamlines;
- experimental stations.

These components are disposed along an essentially linear geometry, 3.4 km long, starting on the Deutsches Elektronen Synchrotron Laboratory (DESY) campus in the north west part of the city of Hamburg, and ending in the neighbouring Federal State of Schleswig-Holstein, south of the city of Schenefeld, where the experimental hall will be located and a lively scientific campus is going to see the light of day (Figure 3.1.1).

The basic functions of the main components are schematically described in the following: In the injector, electron bunches are extracted from a solid cathode by a laser beam, focused and accelerated by an electron radio frequency (RF) gun and directed towards the linac with an exit energy of 120 MeV. In the linac, consisting of a 1.6 km long sequence of superconducting accelerating modules, magnets for beam steering and focusing, and diagnostic equipment, the electrons can be accelerated to energies of up to 20 GeV (17.5 GeV is the energy foreseen for normal operation of the XFEL Facility). At the end of the linac, the individual electron bunches are channelled down one or the other of two electron beamlines by the beam distribution system (Figure 3.1.2).

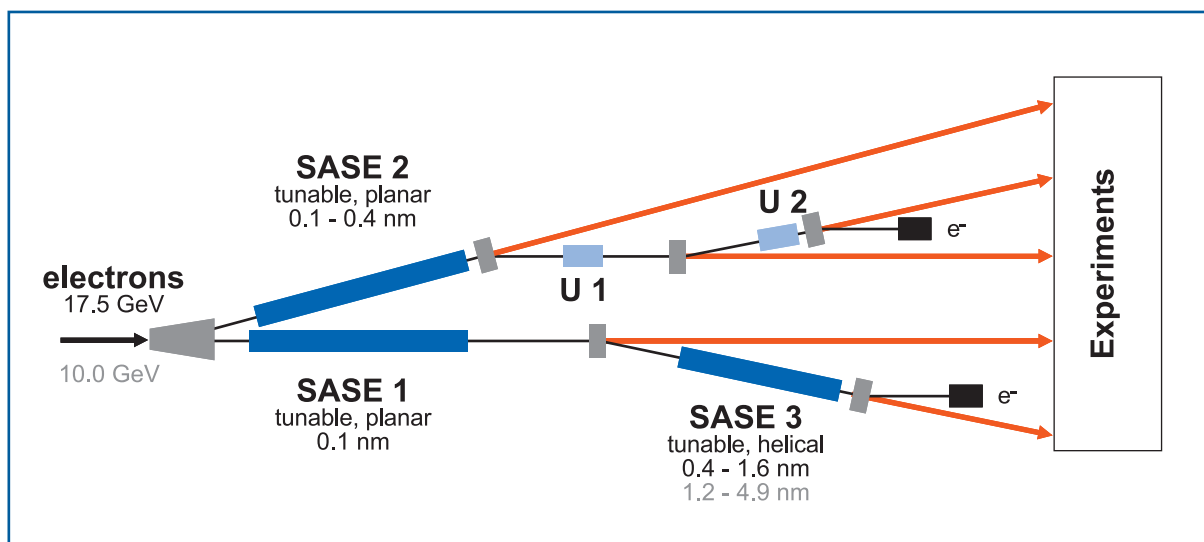
## General layout of the XFEL Facility



**Figure 3.1.1** General layout of the European XFEL Facility, from the injector building on the DESY campus to the experimental hall located in Schenefeld. The branching of tunnels is described in the text.

## General layout of the XFEL Facility

Electron bunches channeled down the electron beamline 1 pass through the undulators SASE 1 and SASE 3, producing respectively hard x-ray photons with 0.1 nm wavelength (SASE 1) and softer x-ray photons with 0.4 - 1.6 nm wavelength (SASE 3), by the Self-Amplified Spontaneous Emission (SASE) free-electron laser process. After going through SASE 3, electrons are deviated towards a beam dump, composed of a graphic core and a large water-cooled copper block. Electron bunches channeled through the electron beamline 2 are led through the undulator SASE 2, where hard x-ray photons with wavelengths 0.1 - 0.4 nm are produced by the SASE process; and then through the undulators U 1 and U 2, before ending in the second beam dump. In U 1 and U 2, very hard x-ray photons (wavelengths down to 0.025 and 0.009 nm, respectively) are generated by the spontaneous emission process. The photons generated by the five undulators are transported through the respective photon beamline to the experimental hall, where each beamline feeds two experimental stations.



**Figure 3.1.2** Schematic view of the branching of electron (black) and photon (red) beamlines through the different SASE and spontaneous emission undulators. Electron beamlines terminate into the two beam dumps, photon beamlines into the experimental hall.

## 3.2 Injector

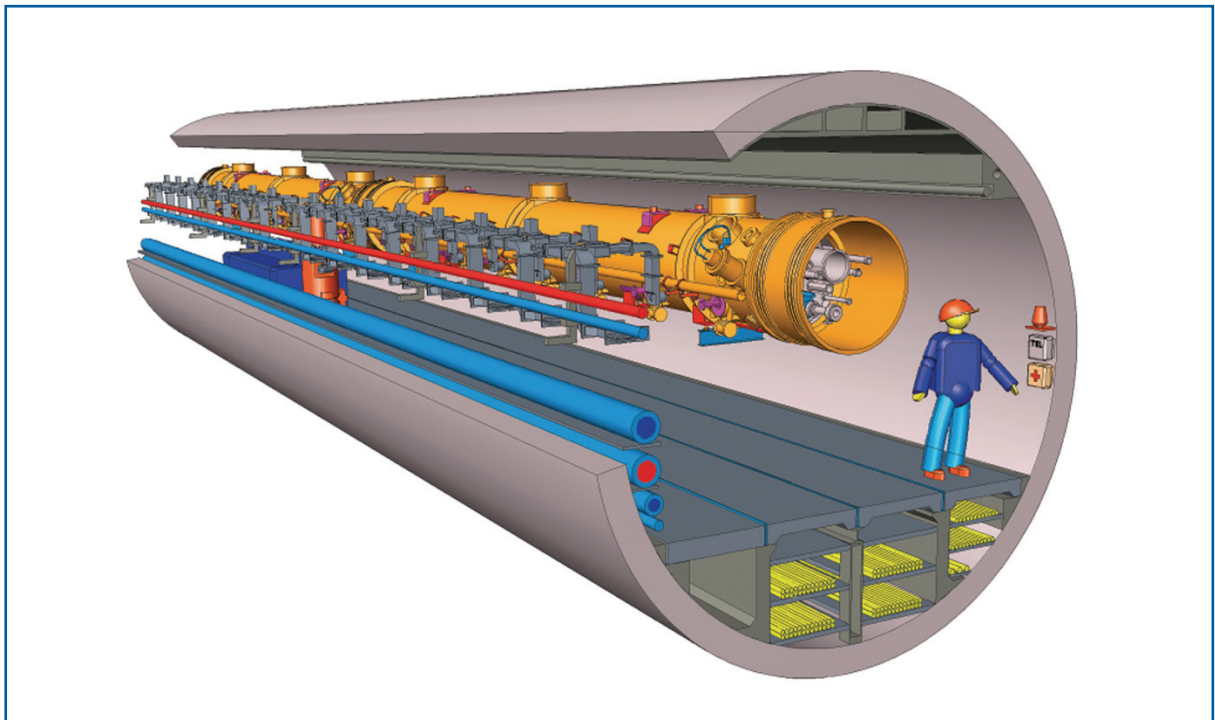
The injector is located in a building on the western part of the DESY campus, just inside the PETRA ring perimeter. It is part of a complex of new buildings where also the modulators for the RF system, the cryogenic plant and other technical components are located. The injector building has four underground floors, devoted to housing auxiliary equipment, above the injector itself, located at a depth of about 27 m below the ground. Although the installation of only one injector system is foreseen within the present project, space is foreseen for a second, parallel injector system, located directly above the first one, which could be used later to increase the uptime of the facility for the benefit of the users. The main components of the injector are the gun, composed of a photocathode, from which a visible laser extracts electron bunches, which are then subject to a high accelerating gradient; a system of accelerating cavities which accelerate the electrons up to 120 MeV;

## General layout of the XFEL Facility

and a series of focusing and diagnostic equipment to ensure the necessary beam quality (low emittance, low energy spread, etc.) which is extremely important for the whole XFEL operation. The total length of the injector is about 66 m, after which the electrons are delivered into the linear accelerator.

### 3.3 Linear accelerator

The linac is located in a tunnel (Figure 3.3.1) which starts from the underground injector building, runs horizontally below the ground, and ends about 2 km further at the location of the beam distribution system. The tunnel, with a diameter of 5.2 m, is horizontal but, since it runs below a slightly sloped ground, is located at a depth below the surface which varies from place to place between 38 m and 15 m. The linac occupies the first 1.6 km of the tunnel. Most of the length is taken by the 116 accelerator modules, each 12 m long, which are necessary to bring the electron energy up to 20 GeV. Further essential components are the two bunch compressors, arrays of magnets with the purpose of shortening the bunch length to about  $55\text{ }\mu\text{m}$ , which corresponds to a duration of less than 200 femtosecond. The first bunch compressor is located at the point where the electron energy is 0.5 GeV, the second at the energy of 2.0 GeV.



**Figure 3.3.1** Schematic section of the linac tunnel. The accelerating modules (yellow) are suspended from the ceiling, for more convenient access and economy of floor space.

The last 0.4 km of the tunnel are occupied by equipment which has the purpose of delivering a well collimated and aligned beam to the following stages of the FEL and notably to the undulators. It is composed of diagnostic equipment, quadrupole and sextupole magnets and horizontal and vertical kickers.

### 3.4 Beam distribution system

The XFEL linac can produce 10 RF pulses per second, each of 600  $\mu$ s duration, and each pulse can accelerate a train of up to 3,000 electron bunches, i.e. with a minimum spacing of 200 ns between successive bunches. The users have, in principle, a wide variety of possibilities as the filling pattern can vary from a single or few bunches per train to full trains of 3,000 bunches. Since the facility is meant for simultaneous use of many experimental stations by different groups of users, who may have contradictory requirements, the maximum flexibility corresponds to a system of fast kickers, able to direct individual bunches to one or the other of the two electron beamlines and, therefore, through different sets of undulators.

The system of fast kickers that directs electron bunches through the undulator SASE 1 or SASE 2 (see Figure 3.1.2) is located close to the residential area of Osdorfer Born, a building that provides access to the equipment, which reaches approximately 15 m below the ground. Here, provision of space is made for the later addition of a third possible direction for electron bunches: should it be decided that more experimental stations are needed than the ten initially foreseen, a third tunnel can be added to those of SASE 1 and SASE 2; this transfer tunnel, already realised during construction phase 1, can be used to lead the electrons to an additional series of undulators and experimental stations.

It should be added that downstream along the SASE 1 line, further access to the tunnels is foreseen, to serve the point where electrons are directed through the SASE 3 undulator, while SASE 1 photons continue along their straight path in a separate tunnel. Downstream, along SASE 2, there are also two accesses, one where electrons are deflected to go through the U 1 undulator, and the other where they are further deflected to go through the U 2 undulator.

### 3.5 Undulators

Second- and especially third-generation synchrotron sources make use of undulators, to increase the brilliance of their radiation, and considerable expertise has been gained in the design and construction of these insertion devices. The XFEL's undulators, however, differ from conventional ones in that they have lengths exceeding 100 m (SASE 3) and even 200 m (SASE 1 and SASE 2), and very tight tolerances for alignment and uniformity. In order to respond to these requirements, undulators will consist of 5m long modules, separated by 1.1 m long intersections. In the latter, diagnostic and correction equipment for the electron trajectory are located. The minimum magnetic gap for the SASE undulators is 10 mm, for U 1 and U 2 it is reduced to 6 mm, and all devices can be tuned, by opening the gaps. The undulator segment mechanics have been designed that they can be manufactured economically in large quantities.

### 3.6 Photon beamlines

After leaving the electron bunches at the end of the undulators, the photons are still hundreds of metres away from the experimental stations. They cover this distance by passing through tunnels with a diameter of 4.5 m, at a depth between 6 and 13 m under the ground, which lead the photons to the experimental hall (see Section 3.7). Along this path, various pieces of equipment are located which shape and collimate the beam:

- filtering as much as possible of the considerable spontaneous emission background produced, in addition to the coherent FEL radiation, by the passage of the high energy electrons in the undulators;
- monitoring the position of the beam and, in general, implementing photon diagnostics. The last function is particularly important not only for the user downstream, who needs to have a well characterised beam, but also as an essential tool for diagnostics of the components upstream, such as the alignment of the undulator segments, their proper phasing, etc.

Depending on the purpose and the configuration of the experimental stations downstream, some of the optical elements such as mirrors or monochromators may also be located in the tunnel.

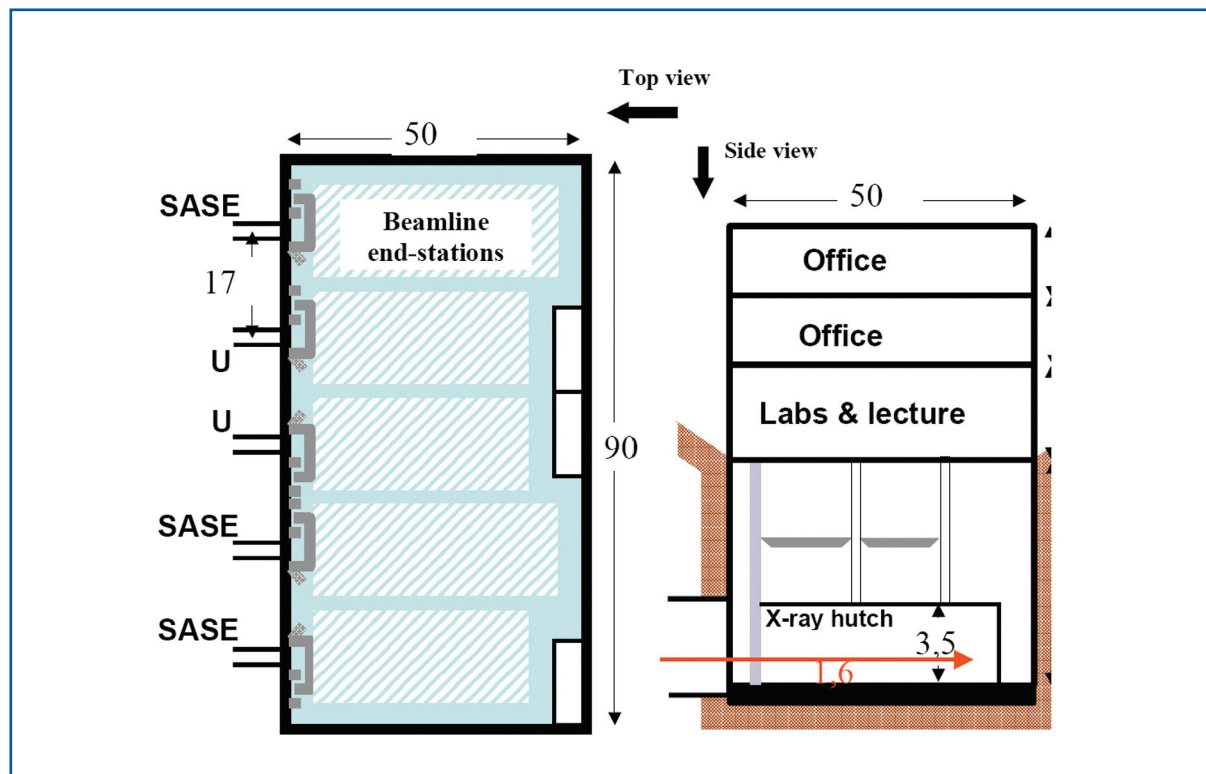
### 3.7 Experimental stations

The experimental stations are located in a dedicated building, which provides access to the underground experimental hall (Figure 3.7.1). In the building, there will be three floors above ground level; with office space on the upper two and preparation laboratories and a lecture hall on the ground floor. The underground part of the building consists of the  $50 \times 90 \text{ m}^2$  hall, where the five tunnels corresponding to the five photon beamlines enter, with a distance of 17 m between them, on the 90 m long side. The several experimental stations fed by one beamline must, therefore, occupy a floor space of  $15 \times 42 \text{ m}^2$  with a 2 m wide transportation way in between them. The 14 m high ceiling will be equipped with heavy-duty overhead cranes; the height of the ceiling allows the installation of very tall hutches for particular experimental requirements.

It is not possible to summarise, in general terms, the experimental stations' equipment. Their detailed design and configuration is determined by scientific use and can vary considerably. Some applications, such as those exploiting the spatial coherence properties of the beam, generally require a reduction in the number of optical elements or to eliminate them altogether, as they lead to some degradation of the coherence. Other applications may require a very bulky sample environment, or sophisticated microfocus optical devices.



## General layout of the XFEL Facility



**Figure 3.7.1** The floor plan (left) of the experimental hall and a vertical cut through the building (right) showing the three floors above ground level and the underground experimental hall.

### 3.8 Schenefeld campus

The successful operation of the European XFEL is expected to attract great scientific interest. A large number of scientists will be using it, and will also visit the facility for other purposes, such as attending workshops and conferences, holding discussions with colleagues and visiting laboratories. Partner institutions may wish to have permanent outstations close to the XFEL, similar to the EMBL outstations at DESY and European Synchrotron Radiation Facility (ESRF), or to the Institut de Biologie Structurale (IBS) next to ESRF. It is very likely to become the object of excursions by schools and university classes, or even by the general public with an interest in science. One can, therefore, expect a development of the whole area around the experimental hall buildings, with all the necessary facilities (auditorium, cafeteria, visitor centre, partner institutes' laboratories). An architectural concept is shown in Figure 3.8.1.

## General layout of the XFEL Facility



**Figure 3.8.1** How the Schenefeld research campus might look in the future. The red arrow points to the European XFEL experimental hall building.