TESLA X-FEL beamline design

Horst Schulte-Schrepping

Hamburger Synchrotronstrahlungslabor HASYLAB
am Deutschen Elektronen-Synchrotron DESY
Notkestr. 85, D-22607 Hamburg, Germany
E-mail: horst.schulte-schrepping@desy.de

Abstract

TESLA X-FEL-undulators will provide highly brilliant coherent radiation with a unique time structure. Possible setups of optical elements in a typical beam-path are shown. Properties of these elements and necessary enhancements of calculations are discussed.

1 Introduction

The TESLA X-FEL-undulators [1] will provide highly brilliant coherent radiation, accompanied by incoherent radiation from the spontaneous emission of the same undulator. Both parts carry the same time structure with a bunch length of 100 fs (σ-value). At a wavelength of 1Å the time averaged flux of the first harmonic coherent line is 5 orders of magnitude larger than the underlying incoherent line. The coherent line will have a peak flux of up to 10^{27}ph/s/0.1% bandwidth with a total number of 2×10^{13}ph/0.1% bandwidth photons in a single bunch.

2 Beamline setup

A beamline setup concentrating on the coherent beam will be a combination of the following components:

source – undulator
attenuators – absorption cell
beam shaping elements – primary slit system, refractive lens
crystal optics – diamond crystal
(re)-focusing optics – mirror, refractive or Bragg-Fresnel lens

The incoherent beam is stopped by an aperture in front of the first optical element. The aperture size should be 2-3 times larger than the coherent beam size in order to avoid diffraction. In fig.2 a possible layout for a future X-FEL site at the TESLA-linear accelerator is shown. Two electron beams with energies in the 10-25 GeV and 20-50 GeV range are each switched between two SASE undulators. After passing a SASE undulator the electron beam is fed through one or two conventional spontaneous undulators, still providing a high spontaneous peak flux due to the unique time structure.

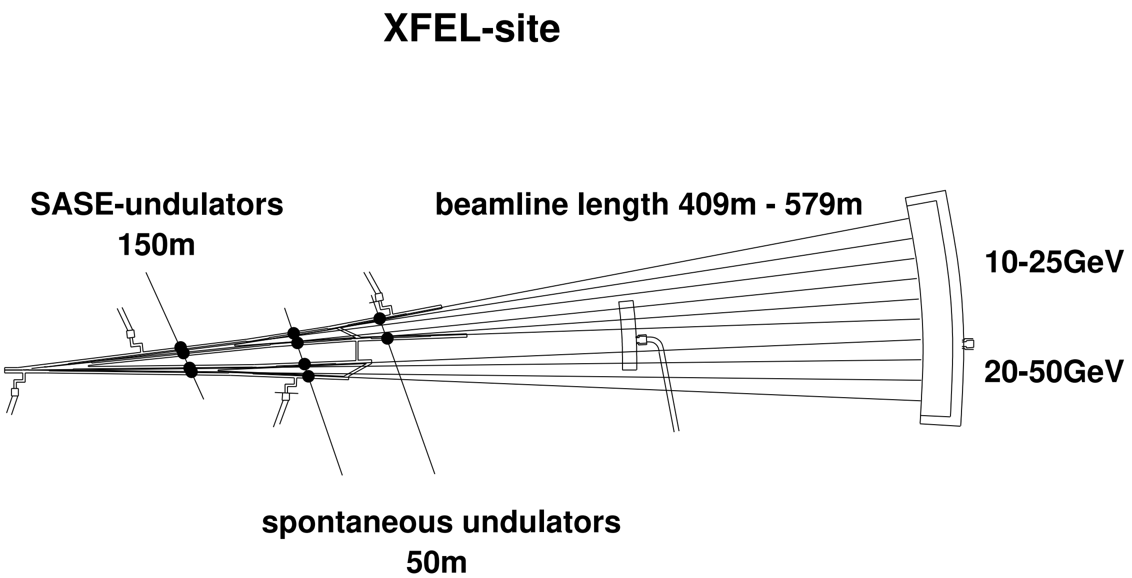

Figure 1: Sketch of a X-FEL site with four SASE (up to 150m long) and six spontaneous undulators (up to 50m long), beamlines, and a common experimental building.

In fig.2 the beamsize of the X-FEL beam is shown at positions relevant for optical elements, including an absorption cell to attenuate the beam.

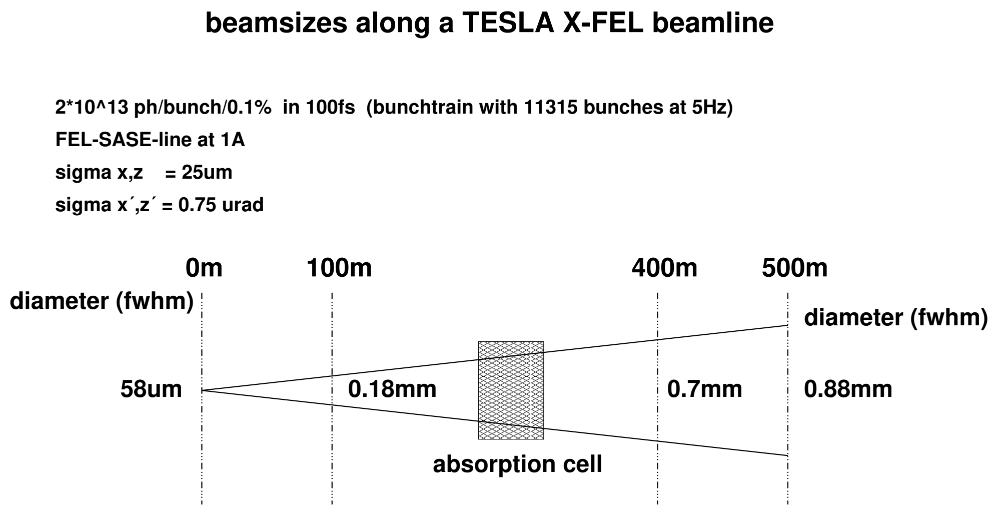

Figure 2: Typical beamsizes along a TESLA X-FEL beampath

In order to preserve the properties of the coherent radiation at the sample position, an unobstructed transport from the undulator to the sample is necessary. The use of normal incidence optical elements, e.g. windows and lenses, should be avoided. In this case the sample is located in a vacuum system connected to the beamline vacuum by a differential pumping stage. Another special differential pumping stage with integrated gas absorption cell provides an attentuation of the beam of up to a factor of 10^4. The absorbing medium is a chopped Xe gas volume with a local pressure at the beam position of 100 to 7000 Torr and an assumed active length of 10mm. The gas stream is synchronized to the bunch train repetition rate to minimize the average pressure and gas load in this part of the system [2].

3 Focusing the X-FEL beam

Focusing of the coherent beam by an elliptical mirror in a distance of 500m from the undulator with a minimum focal length of 5m (100:1) provides a focal spot size of 0.58μm with a convergence at the sample of 0.1mrad. A candidate is a beryllium or diamond like carbon coated silicon body, used at a glancing angle of 2mrad at 1Å . All other means of focusing or collimating the radiation introduces optical surfaces normal to beam path. In these cases the key parameters for a beamline layout are the following:

X-ray refractive lenses [3] and Fresnel zone plates accept a beam with a diameter of up to 1mm. A focal length ranging from 0.1m to 100m for lenses (Be, B, or C) and 1m to 100m for zone plates is technically feasible.

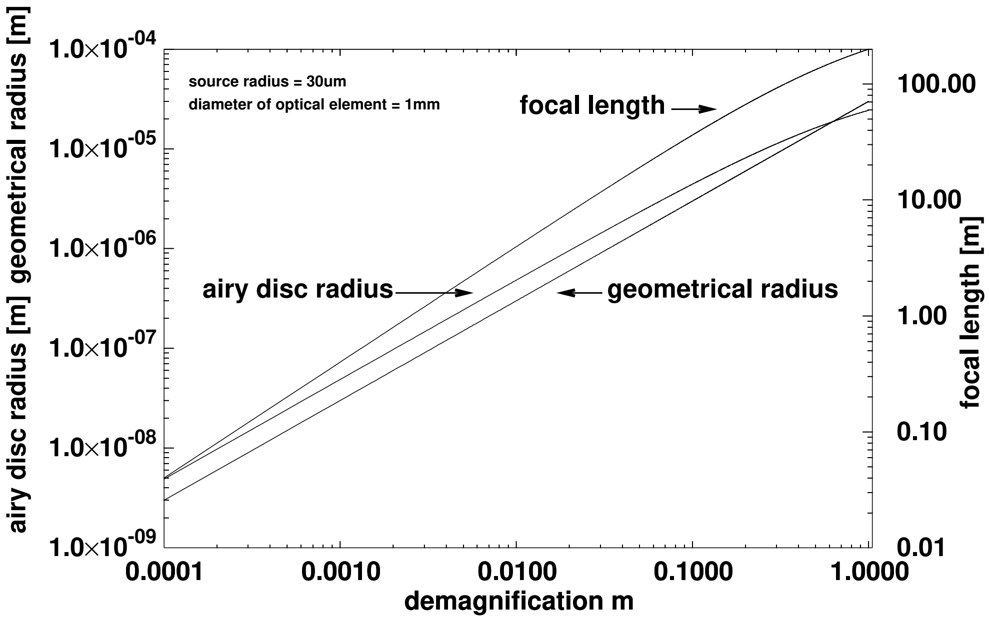

Figure 3: Radius of a focused coherent beam at the focal position for a demagnification ranging from 0.0001 to 1. Shown is the focal length and the focal radius given by geometrical optics, and the radius of the airy disc. Assumed is a radius of the source of 30μm, and a diameter of the optical element of 1mm.

The focal size is determined by the coherence and natural collimation of the beam. The diffraction limited focal size will be larger than the size given by the geometrical demagnification. In the case of zone plates, the minimal width of the outer zone plate ring of approx. 100nm limits the minimum focal size.

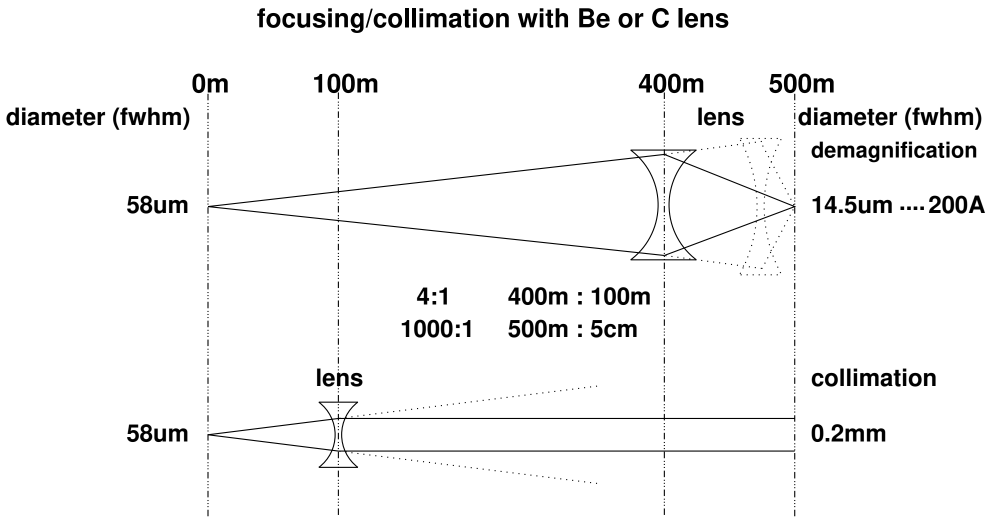

Figure 4: Refractive lenses used for collimation or focusing of the X-FEL radiation, distances and focal sizes are based on the geometrical optics limit

4 Monochromator

The monochromatization will be done with a Laue case diamond crystal close to the sample position. To keep the power density of the direct XFEL beam at a tolerable level, either the beam is attenuated by the absorption cell or spread by a toroidal mirror. Additionally the Laue-case geometry also naturally focuses the beam. A second diamond crystal will be used to compensate the chromatic aberrations of the first crystal [4].

5 Modelling the properties of optical elements in a X-FEL Beam

Efforts are under way to adapt high power laser computer codes to the x-ray regime. This codes will be used to perform damage calculations for optical elements and all kind of materials illuminated by the intense X-FEL beam.

The degree of accuracy of a X-FEL beamline design and the analysis of the theoretical performance by using geometrical considerations or ray-tracing codes[5] is limited. The small source size, high collimation of the X-FEL beam, and the high degree of coherence gives rise to diffraction in all types of optical calculations. This asks for the more general approach of a wavefront calculation. There is a program available for the soft x-ray regime [6]. The evaluation of this program for calculated X-FEL wavefronts is under way. The SRW-code [7] developed at ESRF is another candidate for this kind of calculations.

A detailed study of the use of refractive lenses for X-FEL sources and the limits of focusing of a coherent beam is necessary. The propagation of ultra-short pulses through matter and the dynamical diffraction of x-rays in crystals is another topic not yet implemented in wavefront codes.

References

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