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Technical Concepts Scope for SASE4/5

Scope of proposed concepts from the workshop "Shaping the future of the European XFEL: options for the SASE4/5 tunnels" held at the European XFEL, Schenefeld, December 6-7, 2018

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1. A hard and ultrahard X-ray source based on conventional undulator technology and advanced lasing options

Scope

Production of partially coherent X-ray pulses up to 50-70 keV using a standard SASE on the fundamental and up to about 100 keV with harmonic lasing or other advanced options. With the standard compression scheme the number of photons per pulse would be on the order of 10^9 at about 100 keV and 10^{10} in the 50-75 keV range. Application of advanced compression schemes, based on laser modulation in front of the undulator (eSASE), would allow increasing the number of photons by an order of magnitude. Degree of transverse coherence depends on electron beam emittance, and can range from 20% to 50% at 100 keV, and from 40% to 80% at 50-75 keV (assuming emittances of 0.3 μm and 0.2 μm). Bandwidth depends on details of the electron-beam formation and transport system, and can be in the range from 0.02 % (intrinsic bandwidth of harmonic lasing, might be hard to achieve due to energy chirp) to a few 0.1%. Tunability range for 17.5 GeV would be from 8 keV to 50-70 keV on the fundamental and up to 100 keV with advanced lasing schemes. Broad tunability would allow serving two users stations: a standard hard X-ray range (8-25 keV) and an ultrahard energy range (25-100 keV) station with possible day/night switching.

2. An ultrahard X-ray source based on in-vacuum undulator

Scope

Production of partially coherent X-ray pulses up to about 100 keV. With the standard compression scheme the number of photons per pulse would be on the order of 10^9 at this photon energy and 10^{10} in 50-75 keV range. Application of advanced compression schemes, based on laser modulation in front of the undulator (eSASE), would allow increasing the number of photons by an order of magnitude. Degree of transverse coherence depends on electron beam emittance, and can range from 20% to 50% for 100 keV, and from 40% to 80% for 50-75 keV (assuming emittances of 0.3 μm and 0.2 μm). Bandwidth depends on details of the electron beam formation and transport system and can be in the range from 0.03% to a few 0.1%. Tunability range for 17.5 GeV would be from 40 keV to 100 keV.

3. A hard and ultrahard X-ray source based on the superconducting undulator technology

Scope

Production of partially coherent X-ray pulses with energy up to 100 keV and the following parameters:

- Pulse duration: ~10 femtoseconds;
- Bandwidth: ~0.3%;
- Polarization: linear

Numerical simulation results:

100 keV : ~10^9 ph, spatial coherence ~15%
75-50 keV : ~10^{10} ph, spatial coherence ~40-60%

Radiation parameters heavily depend on the electron beam quality and might be improved. Here an electron beam emittance of 0.3 μm is assumed. Application of advanced compression schemes, based on laser modulation in front of the undulator (eSASE), would allow to increase number of photons by an order of magnitude [E.Schneidmiller et al.]. For a 20 mm undulator period such techniques as period doubling and harmonic lasing allow to access photon energy range of 1 – 100 keV with 17.5 GeV electron beam.

4. Soft X-ray FEL line with extended user capabilities

Scope

- Extended tunability range at a fixed electron energy (up to factor of 8 for upper boundary of the operating wavelength range with respect to SASE3).
- Extension of wavelength range towards lower photon energies.
- Extension of user capabilities with pump-probe experiments using independent FEL colors in the whole range.
- Full polarization control.
- Capabilities to generate ultimate radiation pulse energies in a Joule range.

Advanced option of radiation generation like Self-Seeding, Harmonic Lasing Self-Seeding (HLSS), maybe HGHG or EEHG (at longer wavelengths) can be implemented as well. These options allow for a significant increase of the coherence time.

5. External Seeding using EEHG or cascaded HGHG

Scope

Use High-gain Harmonic Generation or Echo-Enabled Harmonic Generation to get laser-like radiation. The wavelength could be down to 2 nm and the repetition rate up to 100 kHz. Running at an electron beam energy of 8.5 GeV, cascaded HGHG shows a peak power of about 50 GW at 600 eV (2 nm), with a pulse duration around 6 fs (or 300 μJ) with a 0.08% bandwidth. EEHG simulations show similar parameters at 230 eV (5.4 nm). Studies at shorter wavelengths are ongoing.

6. THz Coherent radiation generation with spent FEL beam

Scope

Use of the electron beam, which has already produced FEL radiation, in order to radiate coherently at wavelengths longer than the bunch length by using an additional, long-period undulator. Depending on the charge of the electron bunch, one could generate pulse energies of 100 μJ (at 20 pC) up to several mJ (at 500 pC) in the 3-50THz range. In order to have the THz pulse before the FEL pulse, a two-bunch scheme is proposed that allows for variable delay between the two maintaining the high timing stability.

7. Superradiance for X-ray Production

Scope

Use chicanes, integrated in the undulator structure in combination with a manipulation of the electron beam, to generate high power, very short pulses comparable to the coherence time. The peak power that can be achieved this way is an order of magnitude higher than normal. Simulations for the PSI case show sub-femtosecond pulses with TW of power can be achieved in the nanometer range, but the method is in principle scalable to the European XFEL case and relative photon energies.

8. X-ray oscillator (XFELO)

Scope

Use one of the SASE4/5 tunnel to build up an X-ray oscillator setup. Simulations indicate that e.g. at 12 keV, a pulse energy of 2.2 mJ in a bandwidth of 28 meV can be obtained (30 m undulator length, 20 passes, energy in cavity: 9.4 mJ, pulse width 320 fs, bunch charge 1 nC). The possible photon energies are close to diamond back reflecting energies. With additional Bragg crystals, a tunability of 10^{-3} can be achieved. The XFELO source would be ideally suited for inelastic scattering methods on ionic or electron systems with meV energy resolution, providing more than two orders of magnitude more spectral flux than a regular SASE source.

9. Self-Seeding addition

Scope

Self-seeding schemes are relatively minor additions to existing or newly to be built undulator set-ups. They allow increasing the spectral brightness of the FEL up to an order of magnitude and can be effectively coupled with tapering schemes. Based on simulations, photon energy ranges with nominal electron beam cover 0.3-1 keV (soft X-ray range) and 3-15 keV (hard X-ray range). Extensions to about 30 keV may be possible using harmonics.

10. THz Radiation generation based on a separate facility

Scope

Install a small high-gain high-repetition rate FEL to produce IR/THz radiation for pump-probe experiments at the end of the photon-tunnel(s) or in the experimental hall. Target frequencies > 3 THz. Simulated FEL performance at 3 THz with simulated electron beam: 2.3 mJ/pulse; 22 ps FWHM; Bandwidth: 7e-2 FWHM. Simulated FEL performance with beam from experiment: 1.4-2 mJ/pulse; 17-30 ps; Bandwidth: $7 \cdot 10^{-2}$-$22 \cdot 10^{-2}$ FWHM. Improvement with respect to SASE by using pre-bunched electron pulses are under study.