SPONTANEOUS RADIATION CALCULATIONS FOR THE EUROPEAN XFEL

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Abstract

Calculating spontaneous radiation emission from long undulator sections such as those present in the European XFEL is important for several diagnostics and science cases. For realistic setups, and including effects of electron beam focusing, emittance and energy spread in the electron beam, these calculations should be performed numerically. We present these calculations for several electron beam and undulator parameters performed by various codes.

INTRODUCTION

Spontaneous radiation calculations are necessary for several diagnostics and science cases. In the European XFEL 3 undulators are currently foreseen, SASE1 and SASE2 for hard x-rays in the range of 0.2 - 0.05 nm, and SASE3 soft x-ray undulator with 1.7-0.4 nm. SASE1 and SASE2 consist of 35 5 meter sections, with about 1.1m long intersections containing diagnostics, phase shifters and focusing magnets. SASE3 consists of 21 segments. Undulator segments are 40mm for SASE1/SASE2 and 68mmm period for SASE3 [1]. To keep the electron beam focused and the radiation from separate segments in phase for over more than 100m of SASE3 and more than 200m of SASE1/2, electron beam focusing and phase shifters are introduced. On-axis undulator radiation from very long undulators has narrow bandwidth inversely proportional to number of undulator periods. Effects of emittance, energy spread, and potential errors in all settings will generally results in a significantly broader spectrum. Calculating radiation properties in this case can be done only numerically. XFEL users are primarily interested in the FEL radiation, and spontaneous radiation is often just a background, or used for tuning purposes. However, the information required to predict SR properties accurately – beam parameters, electron optics, undulator field properties, information on alignment – build up the same model from which SASE FEL radiation can be calculated. SR calculations form a part of a larger software framework [2] and will hellp in commissioning and operation of the European XFEL facility. This work outlines the basic calculation results, and a fuller account will be given in a separate publication.

CALCULATIONS

A model is prepared within [2] which can be used by *XCODE/SRW* [2], [3], and *WAVE* [4]. The SR calculation routines perform intensity calculations on a flat screen at a specified distrance for a set of frequencies. The model is derived from the standard XFEL MAD optics model of the undulator line, with additional information such as air coil correctors or phase shifters. Additional effects are implemented as python scripts

- Effects of electron optics: quadrupole misalignments, arbitrary air coil corrector ot phase shifter settings, arbitrary optics settings
- Emittance and energy spread effects by Monte-Carlo and convolution
- Including tabulated field data for undulators
- Effect of quantum diffusion would play a role for large K parameters and largest electron energy. This is however not very relevant for the main purpose of SR calculations, where the whole length of the undulator is not used, and is discussed separate note

Effects of trajectory misalignment

Studies of SASE FEL performance have resulted in setting the trajectory alignment goal to $1\mu m$ in the undulators. Similar to that, the trajectory misalignment will result in spectral broadining of SR. Quadrupole offsets, steerer magnets and beam position monitors are included in the undulator model which can be used to reproduce the desired beam trajecotry and simulate the corresponding SR properties. When used for tuning purposes, radiation from adjacent undulator segments is studied, and the full trajectory information is not required. Beam position and angle and corrector settings can be fitted to reproduce the BPM readings in this case. Trajectory offsets do result in broadening of SR spectrum, if however the $1\mu m$ orbit requirement is roughly met, this effect will be negligible.

Effects of energy spread

The resonant radiation wavelength is

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

and the shift in electron energy would result in a linear response for the spectrum in the XFEL parameter range

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(see Fig. 1) Thus the caluclations can be performed with convolution, as well as with direct Monte Carlo. The E.XFEL beam has a spread of about 1-3 MeV. Results obtained with Monte Carlo method are shown in Figs. 2, 3

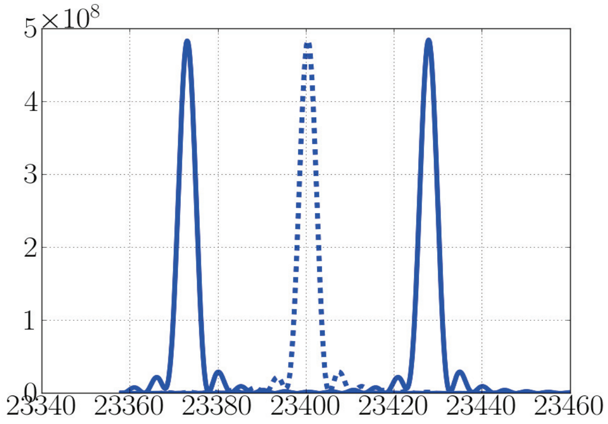

Figure 1: SASE1. 1st harmonic λ=0.05nm with energy offset ± 10MeV

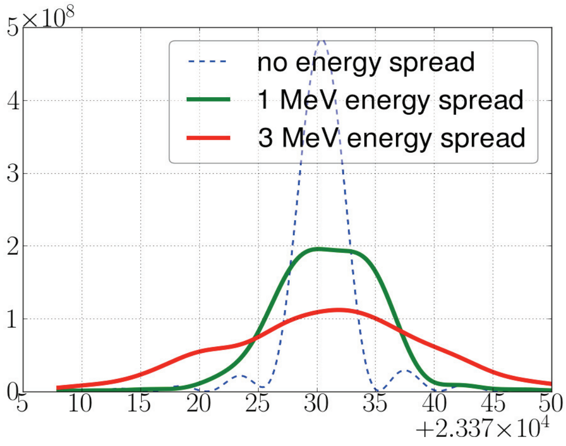

Figure 2: Influence of energy spread on SR in SASE1 undulator, λ=0.05nm, 1st harmonic.

Effects of emittance

With electron focusing, the SR spectrum depends in a nontrivial way on the initial electron offsets and angles, and the effect of emittance is calculated with Monte Carlo. (see. Fig 4). The nominal normalized emittance of E.XFEL is $\varepsilon_{xn} \approx 10^{-6}$. Results for average β of 28m are presented in Fig. 5. Emittance effects can also smear out the radiation profile after a monochromator, see Fig. 6. It is seen that the effect of the emittance is prominent for radiation from the full undulator length. For longer wavelengths, e.g. for SASE3, the effect of emittance is less noticable.

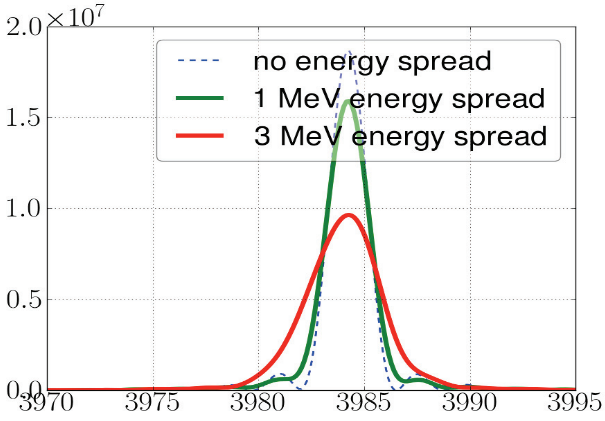

Figure 3: Influence of energy spread on SR in SASE3 undulator, λ=0.3nm, 1st harmonic.

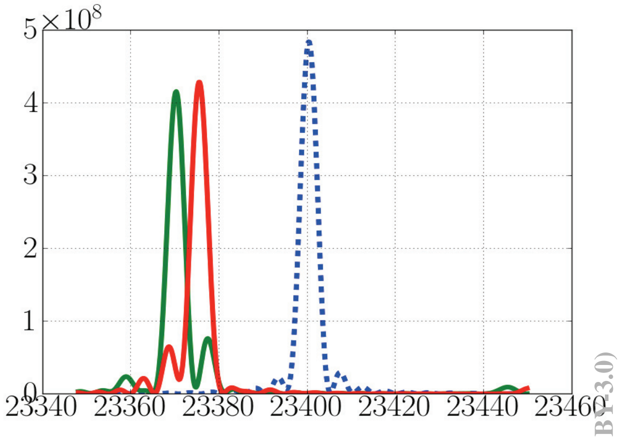

Figure 4: SASE1. 1st harmonic λ=0.05nm, spectrum change resulting from initial electron offsets $x' = \pm 1.5\mu m$

Effects of field non-uniformities

All undulator fields will have some deviations from a purely sinusoidal field, within specification coming from the FEL performance requirements. The remaining field integrals will be compensated by air coil correctors. The undulator fields are measured in a laboratory before being shipped to the tunnel (see e.g Fig. 7). SR calculations can be performed taking measured fields into account, since the software supports reading tabulated field data. A database of undulator fields is being assembled and in the future, especially for commissioning, could be used in the simulations. The fields measured in the lab are not necessary the same as those in the tunnel, undulator sorting depends on logistics and is not decided yet, and all fields should lie within the specification so no noticable influence on radiation should be seen. During commissioning, procedures might be needed to detect undulators with poor field quality (which would necessary differ from that measured in the lab), but this question lies outside the scope of this study.

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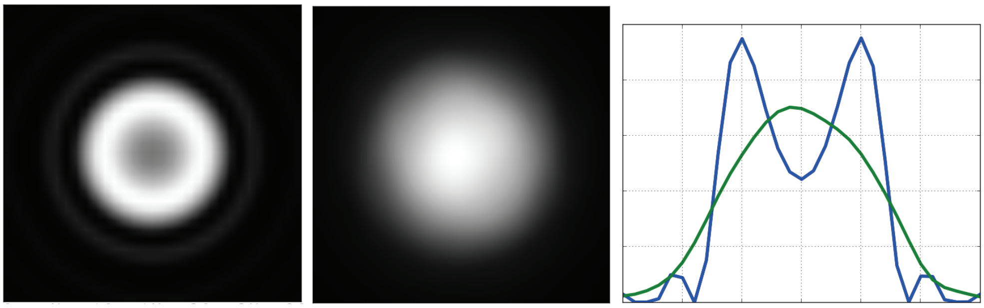

Figure 6: Influence of emittance on a SR image from 2 undulator segments off-resonance after a monochromator

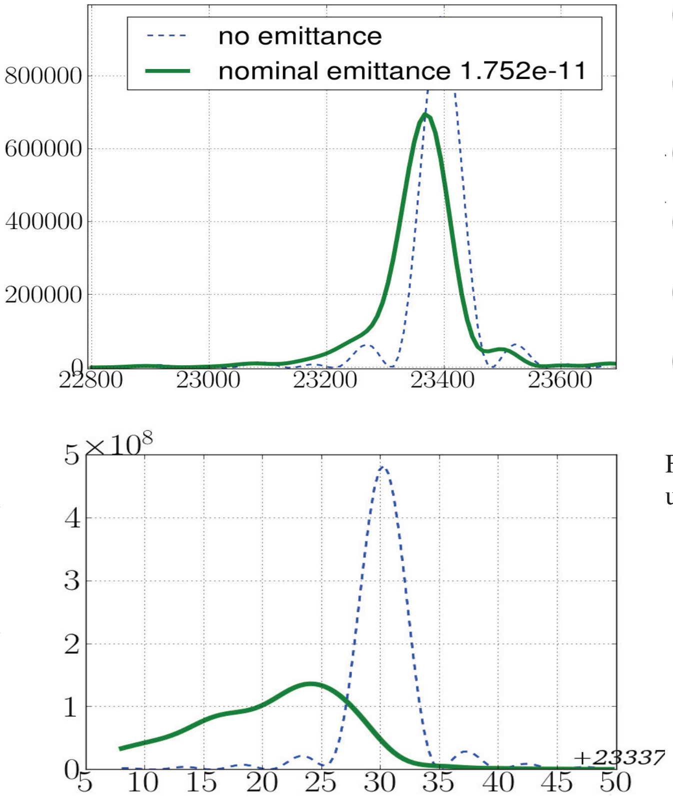

Figure 5: Emittance SASE1, λ=0.05nm, $\langle\beta\rangle = 28m$, two undulator segments (top) and 35 undulator segments (bottom)

ACKNOWLEDGMENTS

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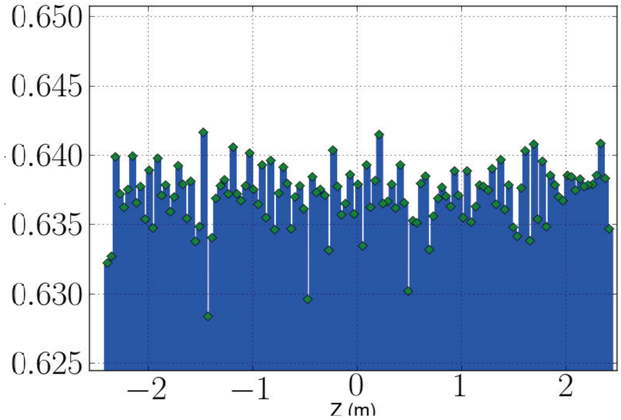

Figure 7: A measured vertical field along one of the U40 undulators, T.

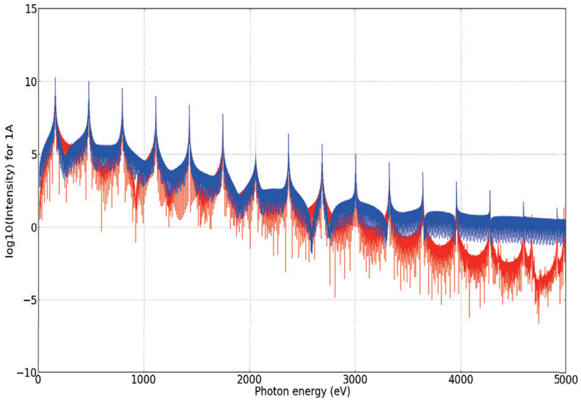

Figure 8: Example of benchmarking SRW vs. Genera, for a single undulator segment, K=1, E=1GeV

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