Beam Loss Simulations for The Implementation of The Hard X-ray Self-Seeding System at European XFEL

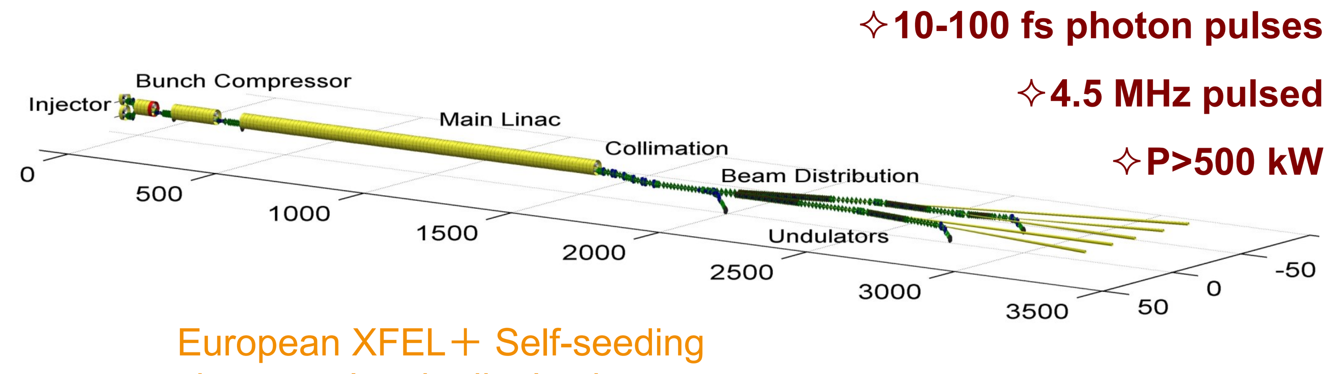
Shan Liu, Winfried Decking, Lars Fröhlich
DESY, Hamburg, Germany

1. Introduction

The Hard X-ray Self-Seeding (HXRSS) is a well-known scheme to increase the X-ray longitudinal coherence in the XFEL. The implementation of HXRSS at European XFEL, however, raises serious radiation damage concern due to the insertion of a diamond crystal close to the electron beam to "filter" the photon beam at high repetition rate (27000 bunches/second). Since the seeding power level highly depends on the delay of the electron beam with respect to the photon beam, it is crucial to define the minimum electron beam offset to the edge of the crystal in the HXRSS chicane. We present the particle tracking simulations performed using GEANT4 and BDSIM, which demonstrate that a minimum offset of 2 mm (~13 fs delay) can be set without significant undulator demagnetization.

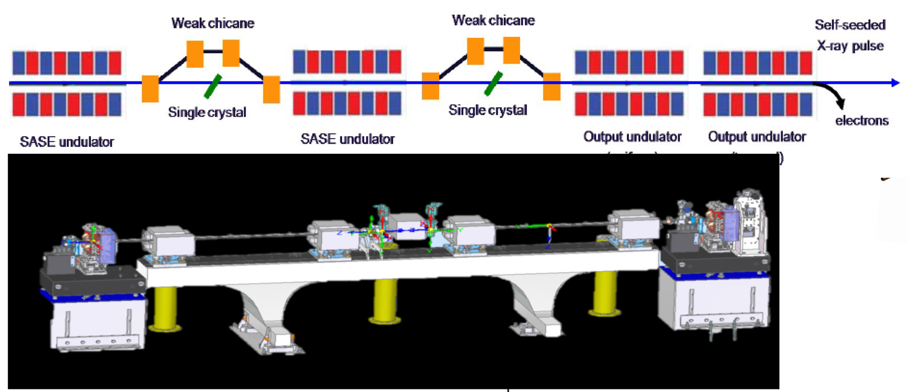
European XFEL [1]

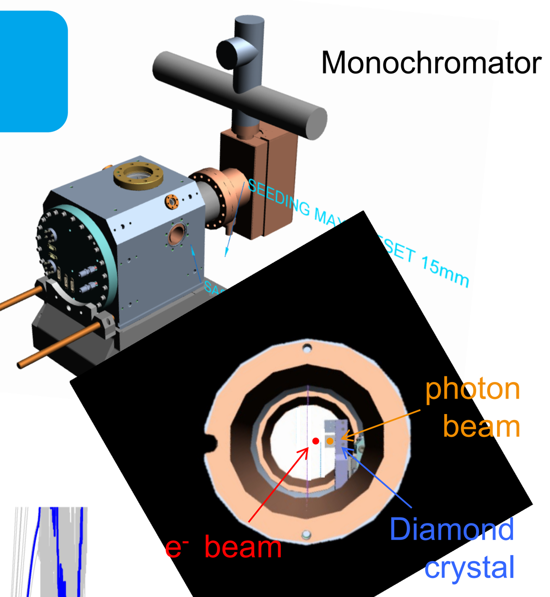
✧10-100 fs photon pulses
✧4.5 MHz pulsed
✧P>500 kW

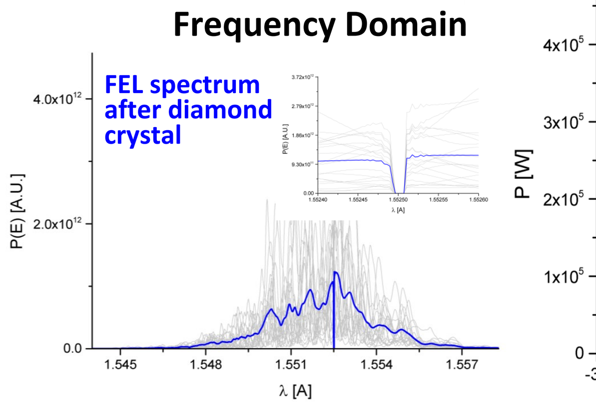


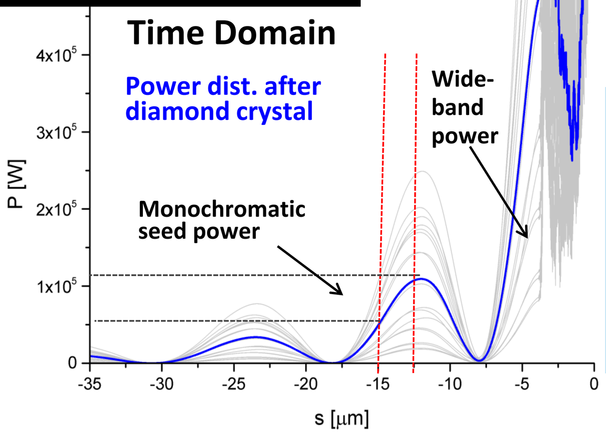
European XFEL+ Self-seeding
➔ increase longitudinal coherence

2. Hard X-ray Self-Seeding[2]





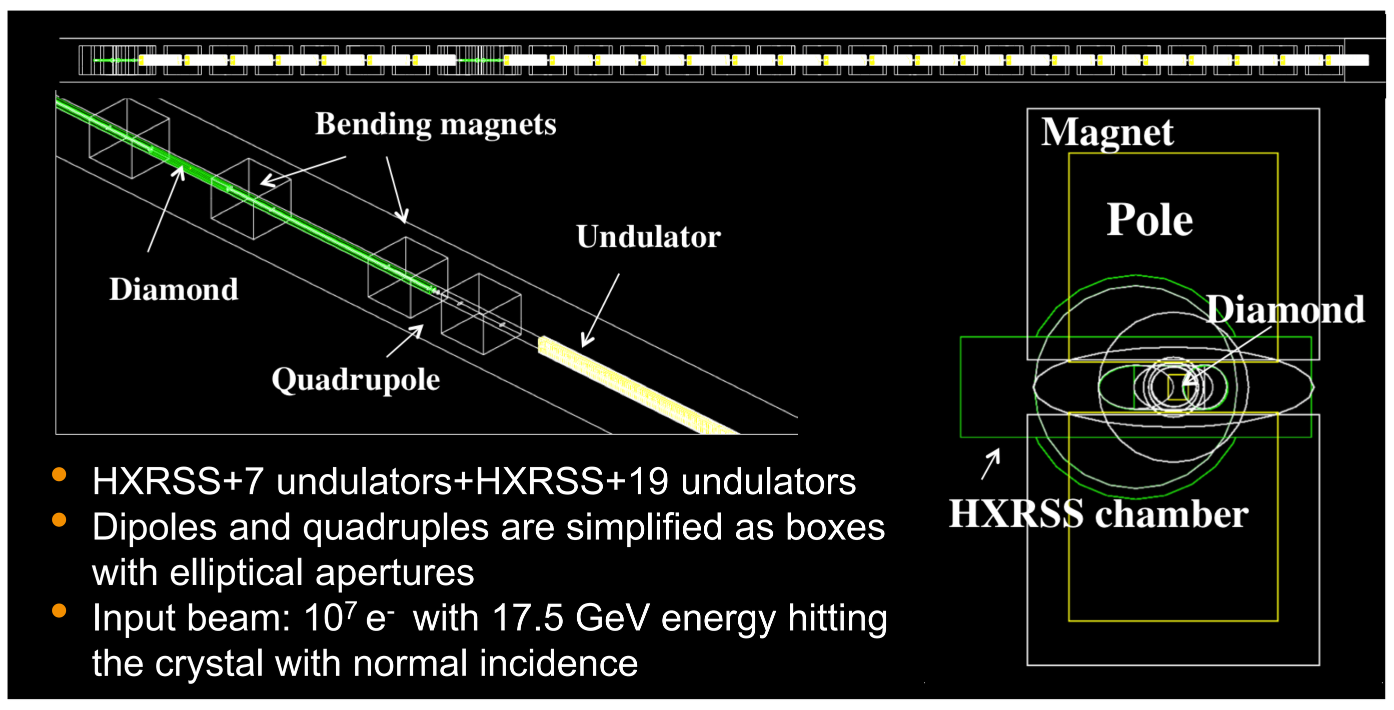




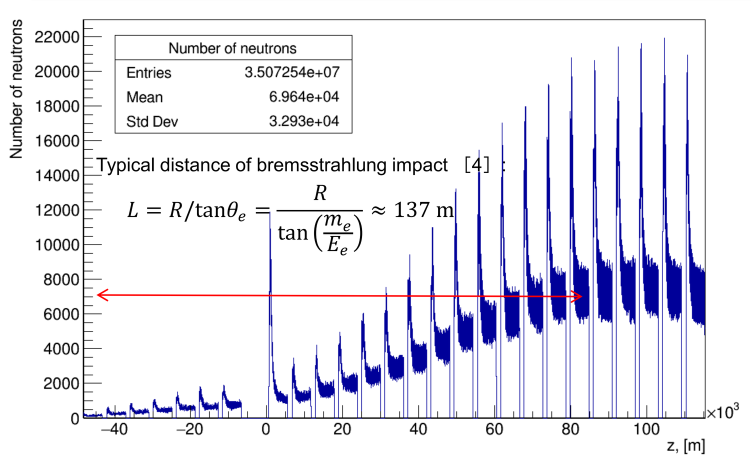
- Chicane delay increase by 10 fs (~0.5 mm increase of offset) -> seeding power can decrease by factor 2!

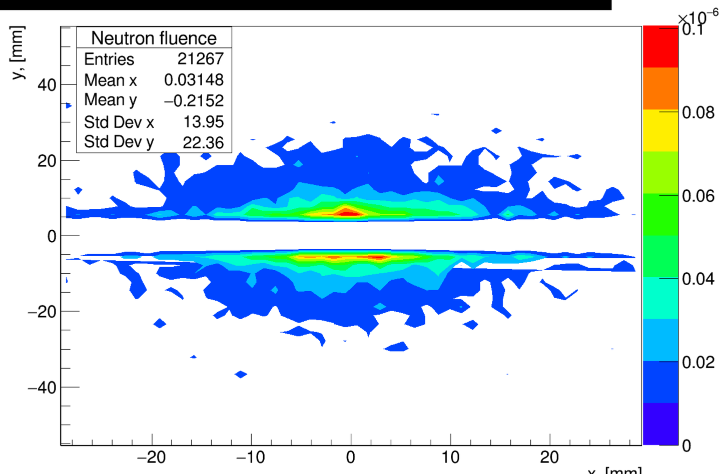
How close the crystal can be to the beam center?

3. Undulator Damage Simulations (GEANT4[3])



- HXRSS+7 undulators+HXRSS+19 undulators
- Dipoles and quadruples are simplified as boxes with elliptical apertures
- Input beam: 10^7 e- with 17.5 GeV energy hitting the crystal with normal incidence





- Max. neutron flux allowed for 0.01 % demagnetization of Nd-Fe-B magnets: 1×10^{11} n/cm^2 [5].
- Assuming 0.01% demagnetization in 20 years with 10 shifts (8 hours each) /month for HXRSS operation, the maximum allowed number of e-/bunch (with 27000 bunches/s):

$N_{critical}=10^{11}/(6.912\times10^7\times27000\times10^{-7})\approx5\times10^5$ e-/bunch and $N_{total}\approx 6.25\times10^9$ e-/bunch

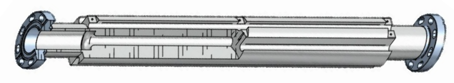
➔ $N_{critical}$ / $N_{total}\approx 1\times10^{-4}$

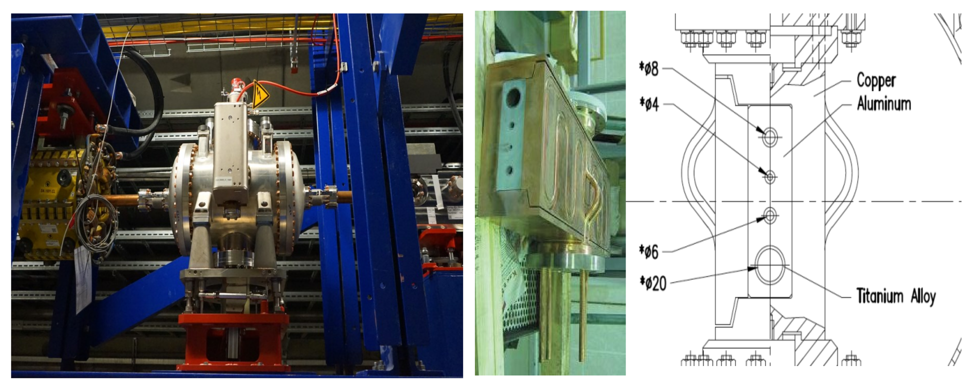
- If there is no halo, the crystal can enter as close as ~4σ ≈ 200 μm to a gaussian beam core!

What if there is 100 σ_x^* of halo?

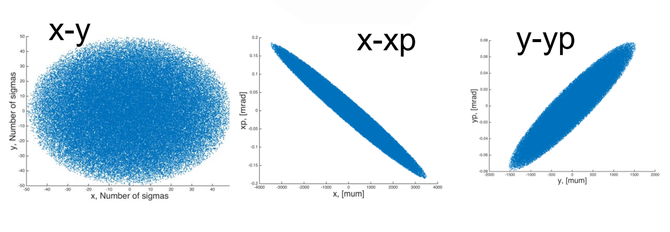
4. Beam Halo Collimation Simulations (BDSIM[6])

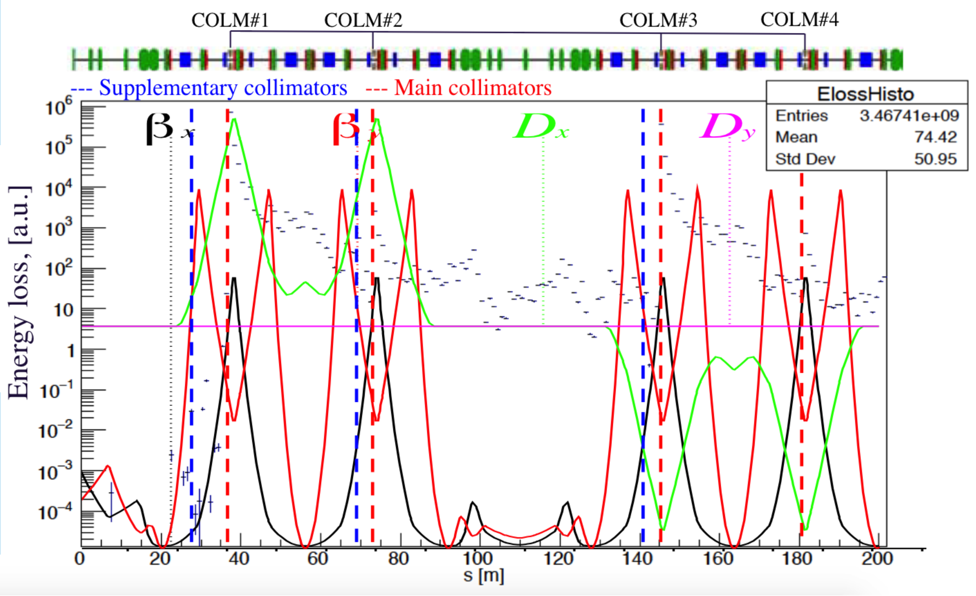
- Around 200 m long collimation section with four main collimators, R=2, 3, 4, 10 mm (Titanium alloy+Al+Cu), L=0.5m and three supplementary collimators aperture: R=10 mm (Al), L=1 m.





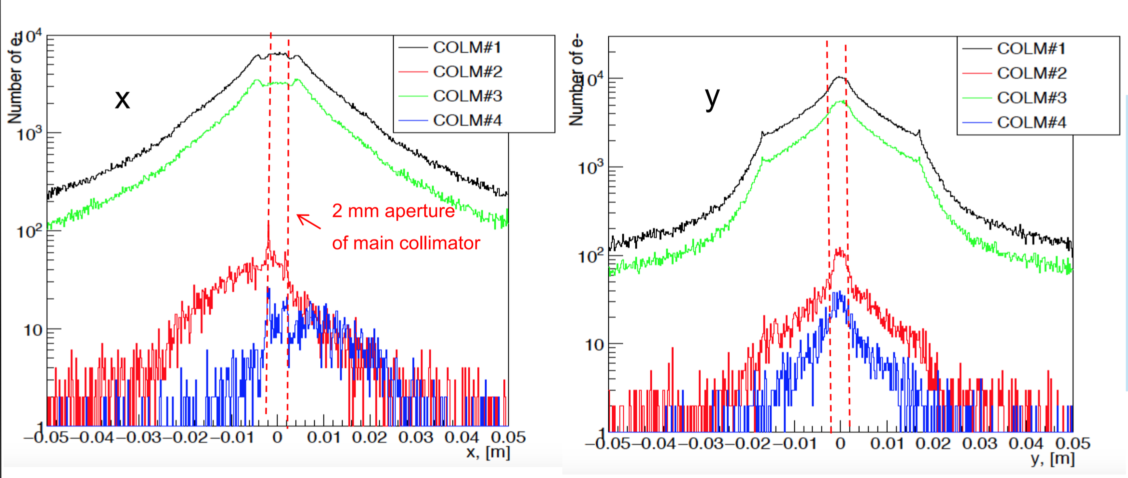
- Input beam halo distribution: 4D uniform in (x,xp,y,yp) phase space with ±50 $\sigma_{x,y}$ [7].





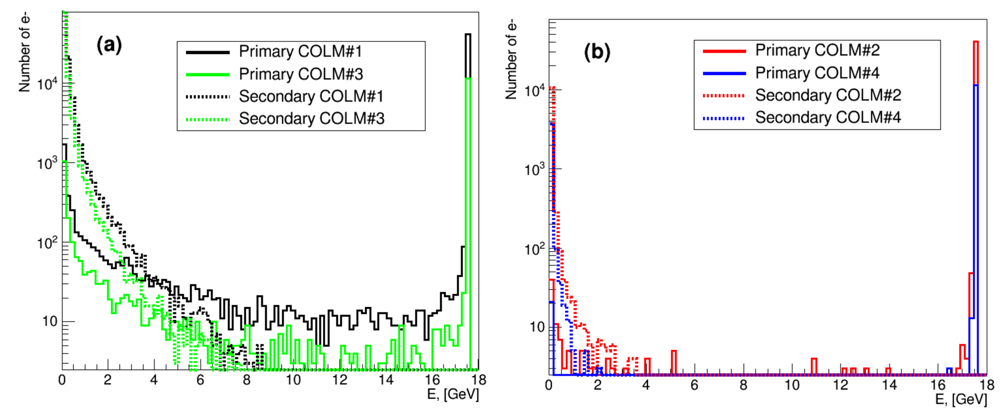
- Energy loss map and the design optics [8] (not to scale) along the collimation section.

2nd electrons distribution

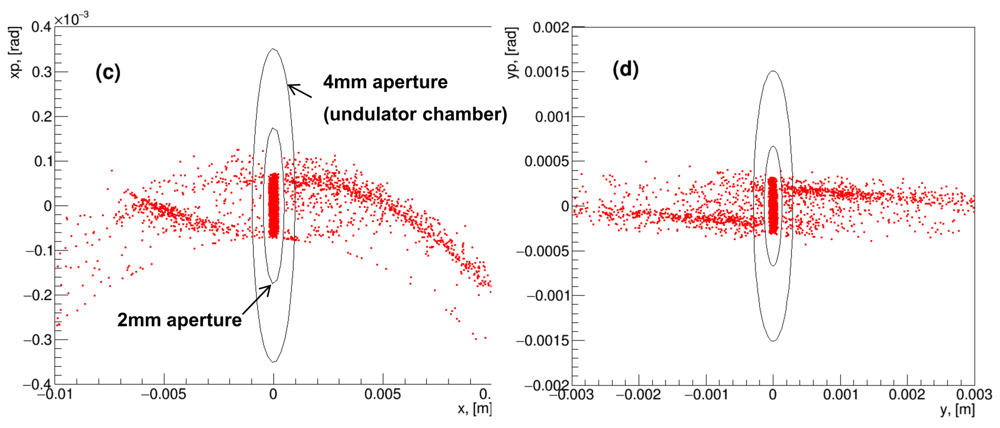


- Primary particles beyond 2 mm aperture are collimated mainly by the first main collimator in the two arcs: COLM#1 (black) and COLM#3 (green).

- Energy distribution of the primary and secondary beam halo particles at the end of COLM#1 and COLM#3 (a) and at end of COLM#2 and COLM#4 (b) with 10^5 input e-. Only those primary e-, which lost a small fraction of their energy (<1.5%), can reach the undulators.



- Phase space distributions at the end of the collimation section for the X (c) and Y (d) plane with 10^7 input e-. Electrons outside the dynamic aperture of the undulator chamber will be stopped at the undulator entrance. The e- between the R=2 mm and R=4 mm apertures are those which may hit the crystal (assuming that the crystal is 2 mm away from the beam center).



N_{hits} is estimated to be 27±6 out of the total number of electrons $N_{total}=10^6$

➔ N_{hits} / $N_{total}\approx 3\times10^{-5}$

The crystal can be inserted up to a distance of ~2 mm to the beam core

(~13 fs of minimum delay) !

5. Conclusions & Prospects

- Geant4 and BDSIM simulations have been performed for the undulator and collimation section, respectively. Simulation results show that the HXRSS crystal can be safely inserted down to 2 mm from the beam center (i.e. a minimum chicane delay of ~13 fs) with the 2 mm collimator apertures;
- Future simulations can be done with more realistic beam halo distributions and also for other applications (e.g. implementation of a corrugated structure with very small gaps (~1.4 mm)).

Acknowledgements

Thanks to colleagues at DESY and European XFEL: I. Agapov, V. Balandin, G. Feng, G. Geloni, N. Golubeva, J. Pflueger and many colleagues from LCLS, especially J. Welch, H.-D. Nuhn and M. Santana-Leitner, for helpful discussions. And thanks to S. Boogert and L. Nevay from RHUL for their support on BDSIM.

*** Reference:**

[1] M. Altarelli, R. Brinkmann *et al.*, DESY 2006-097, 2006.
[2] G. Geloni et al.,*Journal of Modern Optics*, 58(16), pp.1391-1403, 2011
[3] S. Agostinelli *et al.*, *Nucl. Instr. Meth. A*, vol. 506(3), pp. 250-303, 2003.
[4] I. Agapov *et al.*, *Nucl. Instr. Meth. A*, vol. 606(3), pp. 708-712, 2009.
[5] M. Santana-Leitner et al., SLAC-PUB-14020. 2010.
[6] A. Fasso, Radiation Physics Note, RP-05-05, May 2005.
[7] R. Yang *et al.*,*IPAC'16*, paper MOPMB008, pp. 88-91.
[8] V. Balandin et al., TESLA-FEL Report 2007-05, 2007.