

# BEAM LOSS STUDY FOR THE L-SHAPED CORRUGATED STRUCTURE AT EUROPEAN XFEL

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## Abstract

The European XFEL is a free-electron laser facility based on a superconducting linac with high bunch repetition rates of up to 4.5 MHz. An L-shaped corrugated structure has been installed upstream of the SASE1 undulator for fresh-slice operation and ultrashort-pulse generation. As the electron beam passes through the structure, strong longitudinal and transverse wakefields are excited which induce a correlated energy chirp and transverse kicks along the bunch. Since the distance between the corrugated structure and the beam is typically less than 1 mm, any beam misalignment or tail expansion may result in particles hitting the corrugated surfaces. For the L-shaped geometry this may occur on both the horizontal and vertical surfaces. Such interactions lead to energy deposition and secondary radiation that may cause damage to the downstream undulators. For this reason, studies have been carried out using BDSIM to simulate the losses caused by the L-shaped corrugated structure. Simulation results have been compared with in-situ radiation measurements using an autonomous robot.

## INTRODUCTION

The European XFEL employs a superconducting linear accelerator to accelerate electrons to energies of up to 17.5 GeV [1]. It can operate with bunch repetition rates of up to 4.5 MHz within each bunch train. At such high repetition rates, even small beam losses can lead to measurable radiation doses in the downstream beamline, especially in the undulator section [2].

A corrugated structure, also referred to as a dechirper, is a passive device used to manipulate the longitudinal and transverse phase space of an electron bunch through self-induced wakefields. At the European XFEL, an L-shaped corrugated structure [3,4] has been installed upstream of the SASE1 undulator for fresh-slice operation and ultrashort-pulse generation. In operation, the beam is moved towards the inner corner of the structure by local orbit bumps. The L-shaped geometry provides corrugated surfaces in both transverse planes, allowing the structure to generate a correlated energy chirp as well as transverse kicks along the bunch. However, since the typical distance between the beam and the corrugated surfaces is below 1 mm, beam halo, orbit misalignment, or wakefield-driven tail displacement may cause particles to strike the corrugated surfaces, leading to significant downstream losses.

This paper reports work using BDSIM [5] to study particle losses at the L-shaped corrugated structure and the resulting downstream loss pattern. The simulated loss trends are compared with radiation measurements performed with the autonomous MARWIN robot [6]. Experiments were performed to minimize the beam halo population by reducing the apertures of collimators in the dedicated collimation section upstream of the dechirper [7,8]. Under high-repetition-rate operation, the 4 mm aperture setting effectively reduced the measured downstream radiation to a level comparable to the no-bump condition.

## BDSIM SIMULATION

Beam loss simulations were carried out using the BDSIM toolkit. The model starts 53 m upstream of the 6 m long corrugated structure and ends at the exit of the SASE1 undulator, as shown in Fig. 1. The model includes the main beamline components, such as quadrupole magnets, undulator modules, radiation absorbers, and the vacuum chamber aperture transitions into the SASE1 undulators.

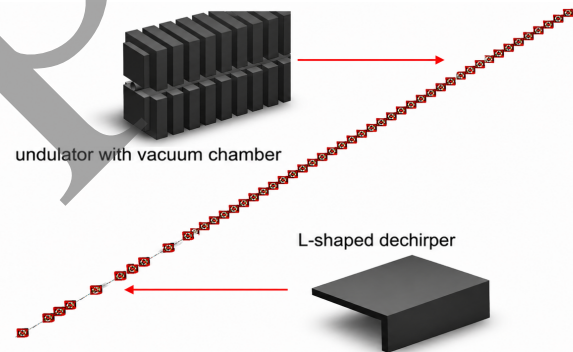


Figure 1: BDSIM model of the L-shaped corrugated structure and the downstream SASE1 undulator line.

A special low-beta optics designed by Qin *et al.* [3] for dechirper operation was used. As shown in Fig. 2, the optics provides small beta functions at the corrugated structure with values of approximately 10 m in both transverse planes. The beta functions shown in the figure were obtained by tracking 1000 Gaussian-distributed particles in BDSIM and are consistent with the designed dechirper optics. This low-beta optics reduces the beam size at the dechirper, allowing controlled orbit bumps that move the beam closer to the corrugated plates.

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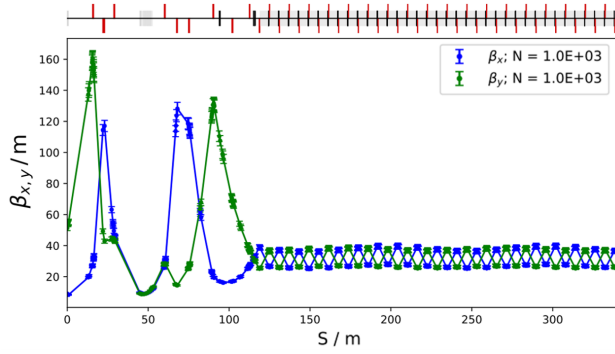


Figure 2: Special low-beta optics used for dechirper operation. The corrugated structure extends from  $s = 53$  m to  $s = 59$  m, and the downstream collimator is located around  $s = 100$  m.

In the simulations, the distance between the beam core and the corrugated surface was fixed at 0.5 mm. The beam parameters used in the simulations are listed in Table 1.

Table 1: Beam parameters for dechirper beam loss simulations in BDSIM.

Parameter name	Value	Unit
Beam energy, $E$	14	GeV
Charge, $Q$	250	pC
Normalized emittance, $\epsilon_x/\epsilon_y$	0.64/1.09	$\mu\text{m}$
Number of primary particles, $N$	$4 \times 10^6$	—
Beam halo start sigma, $\sigma$	$\pm 10$	—
Beam halo stop sigma, $\sigma$	$\pm(25-33.6)$	—

Since BDSIM does not support wakefields, the corrugated structure was modelled as a passive metallic structure and placed close to the beam. This approach allows halo particles to reach the corrugated surfaces, representing possible losses caused by beam halo, orbit bumps, misalignment, or wakefield-driven tail displacement. To study the loss mechanism of the L-shaped geometry, the initial halo distribution was chosen to give approximately equal beam sizes in the horizontal and vertical planes at the corrugated structure entrance. Under this condition, as shown in Fig. 3, the upper and right plates produced similar loss levels, and the L-shaped configuration resulted in approximately twice the loss of the single-plate case.

Particles scattered at the dechirper can develop large-amplitude betatron oscillations downstream, causing losses in the undulator section. To reduce these losses, a collimator is located between the dechirper and the SASE1 undulator. This collimator was originally designed for the single-plate dechirper configuration, and its performance was studied by Guo *et al.* [9]. Since the installed corrugated structure has been changed to an L-shaped geometry, the collimator performance has to be re-evaluated.

BDSIM simulations were performed both with and without the collimator. In BDSIM, the collimator was modelled as an aluminium block of length 0.5 m, with an aperture of 6 mm, located upstream of the SASE1 undulator. As shown in Fig. 4, the collimator reduces the downstream loss

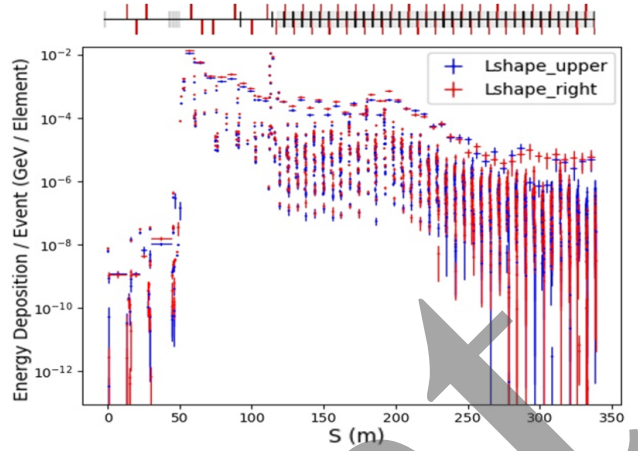


Figure 3: Simulated energy deposition on the upper and right plates of the L-shaped corrugated structure.

peaks by nearly two orders of magnitude. These peaks come from scattered particles with large betatron amplitudes, confirming that the installed collimator effectively intercepts dechirper-scattered particles.

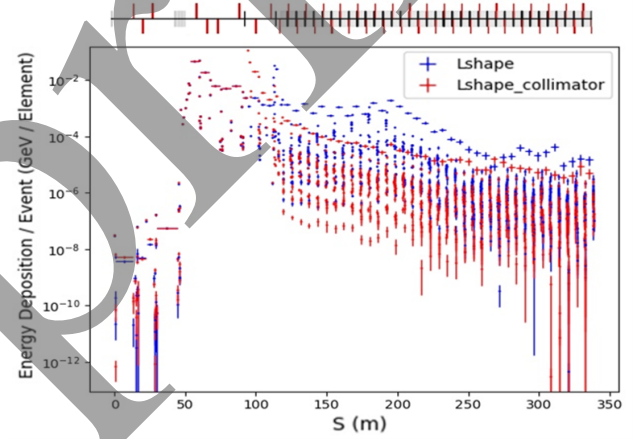


Figure 4: Simulated energy deposition for the L-shaped corrugated structure with and without the downstream collimator.

## RADIATION MEASUREMENTS WITH MARWIN

Radiation measurements were performed using the MARWIN mobile autonomous radiation-monitoring system. MARWIN moves along the tunnel floor approximately 2 m away from the beamline and records the longitudinal distribution of beam-induced gamma and neutron radiation [6]. In this study, MARWIN was used to scan a 200 m long section from 2162 m to 2362 m. This range covers the main loss region after the dechirper, the downstream collimator around 2211 m, and the beginning of the SASE1 undulator line around 2238 m. Orbit bumps were applied to change the horizontal and vertical position of the beam in the L-shaped structure [10]. In the coordinate system used for the bumps, a positive vertical offset moves the beam towards the upper plate, while a negative horizontal offset moves it towards

the right plate and therefore towards the inner corner of the L-shaped structure.

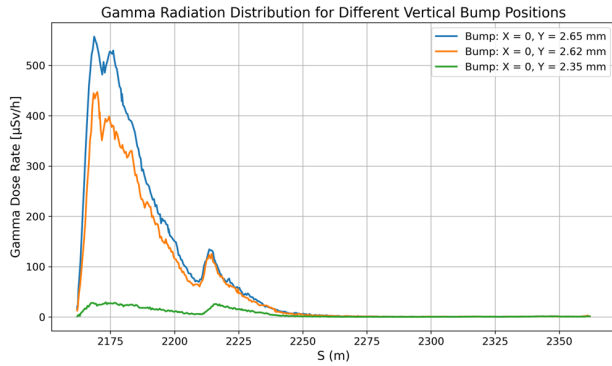


Figure 5: Gamma dose profile measured by MARWIN during a vertical bump scan with fixed horizontal position.

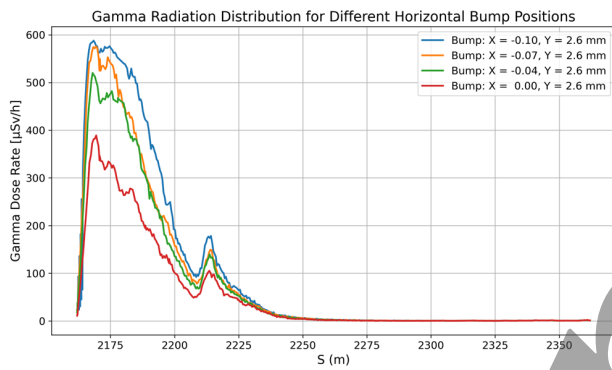


Figure 6: Gamma dose profile measured by MARWIN during a horizontal bump scan with fixed vertical position.

The first measurements were carried in single-bunch operation. This provided a baseline for studying the dependence of the dechirper-induced losses on beam position. Under this condition, no measurable neutron signal was observed, and the analysis therefore focused on the gamma dose profiles. The beam was first moved upward by increasing the vertical bump from  $y = 2.35$  mm to  $y = 2.65$  mm while keeping  $x = 0$  mm. We then scanned the beam towards the right plate by reducing  $x$  from 0 mm to  $-0.1$  mm, with the vertical offset fixed at  $y = 2.6$  mm. As shown in Figs. 5 and 6, the radiation level increased as the beam approached the surface of the L-shaped structure. The first peak observed after 2162 m is attributed to losses at the dechirper, the second peak at approximately 2211 m corresponds to the downstream collimator.

The measurements were then extended to high-repetition-rate operation with 400 bunches per train, as shown in Fig. 7. In this regime, clear gamma and neutron signals were observed because of the increased accumulated beam loss. To mitigate these losses, we reduced the apertures of the four main upstream collimators in the collimation section from 8 mm to 6 mm and then to 4 mm, while keeping the beam bump fixed at  $x = -0.1$  mm and  $y = 2.1$  mm.

After the collimator apertures were reduced to 4 mm, large losses were observed in the collimation section. We there-

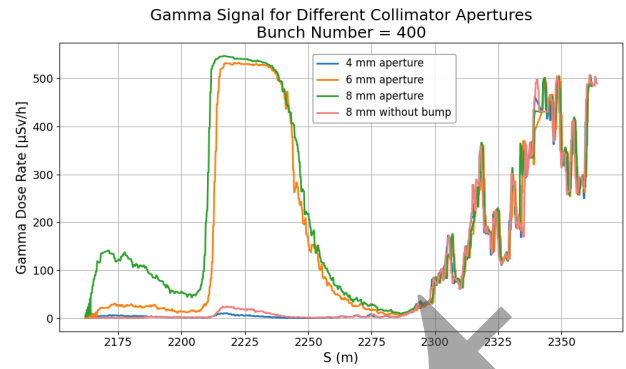


Figure 7: Gamma dose profiles measured with 400 bunches per train for different upstream collimator apertures in the collimation section.

fore re-optimized the orbit through the collimation section while keeping the beam position at the dechirper unchanged. With this optimized orbit, the downstream radiation was strongly suppressed. As shown by the blue curve in Fig. 7, the 4 mm aperture setting reduced the gamma dose rate to a level even lower than the no-bump condition. The neutron signal followed the same trend and decreased to near zero. This indicates that the 4 mm aperture setting can be used to mitigate dechirper-induced losses under high-repetition-rate operation. The reduced aperture in the main collimators removes halo particles that would otherwise be scattered when the beam is moved close to the plates of the dechirper.

## CONCLUSION

Beam losses caused by the L-shaped corrugated structure were studied using BDSIM simulations and MARWIN radiation measurements. The simulations show that the L-shaped geometry produces nearly twice the loss of the single-plate case, while the collimator upstream of the SASE1 undulator reduces the simulated losses inside the undulator section by nearly two orders of magnitude. In single-bunch measurements, MARWIN scans with horizontal and vertical orbit bumps confirmed that the radiation level increases as the beam approaches either corrugated surface. At high bunch repetition rate, we reduced the upstream collimator apertures to 4 mm, which reduced the measured radiation in the dechirper downstream region to a level even below the no-bump condition. These results demonstrate that upstream collimation can effectively mitigate the losses induced by the L-shaped corrugated structure, supporting its use in high-repetition-rate operation.

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