INITIAL USER OPERATION OF SLS 2.0

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Abstract

The year 2025 marked the transition from installation to commissioning and the beginning of first user operation of the Swiss light source (SLS) upgrade, the SLS 2.0. This contribution reports on the achieved storage-ring performance and operational stability. Storage-ring optics were tuned near design, achieving beta beating within a few percent and optimized dispersion. Sub-micron orbit stability was achieved through fast-orbit feedback supported by the inhouse DBPM 3 system, permanent magnets, stable power supplies, and improved environmental control. The injector chain delivered highly reproducible bunch charge, stable energy and optics matching, and transmission exceeding requirements. User operation started with a stable baseline filling pattern and regular top-up injection under defined current-stability conditions. Beamline commissioning progressed in parallel with accelerator-performance optimization, and by the end of 2025 overall 2 diagnostic- and 12 experiment-beamlines were taking light. The achieved machine availability is comparable to the final years of SLS. Operational statistics confirm that SLS 2.0 has rapidly reached a robust operational regime, paving the way for continued performance optimization and full scientific exploitation.

INTRODUCTION

After the completion of the installation phase of the SLS upgrade, the SLS 2.0, and the successful recommissioning of the linac and booster in late 2024, efforts in early 2025 focused on commissioning of the new fourth-generation storage ring [1, 2]. The ring commissioning succeeded rapidly with first electrons injected on the 14th of January, first stored beam on the 23rd of January and design beam current achieved on the 3rd of April. Reaching this milestone ahead of schedule allowed fast beam-dose accumulation for vacuum scrubbing and created favourable conditions for further optimization of injection, orbit feedback, and beamline commissioning at full beam current. After the successful machine commissioning to nominal beam operation parameters within 50 days the focus was shifted to beamline commissioning and user operation. The overview of the beam current development during 2025 given in Fig. 1 nicely shows the rapid progression to stable operation.

BEAMLINE COMMISSIONING

Following the achievement of nominal beam parameters, beamline commissioning focused on the rapid delivery of first light and safe operation permits for user beamlines. It commenced with the permanent magnet superbend beamlines, Debye [3] and PXIII [4], opening their shutters on the 10th of April for first light after 2 days of shutdown for preparing their front-ends (FEs) and personnel safety system (PSYS). Front-end installation was not fully completed during the darktime. It was split into multiple phases [5] which are ongoing in parallel with machine commissioning and operation [6]. For first light the machine started at 60 mA enabling the beamlines Debye [3] and PXIII [4] to open their FE-shutters with little risk and align their beamline elements to get the beam safely to the photon shutter at the end of their optics hutches. Then the beam current was ramped up to the nominal 400 mA. In parallel the radiation protection officers measured the radiation around the optics hutch to ensure that the thresholds are not exceeded and confirm correct function of the implemented radiation shielding. In the next step the photon shutters at the end of the optics hutch were opened bringing synchrotron radiation into the experimental hutch towards the end station. Radiation surveys were then performed around the experimental hutch.

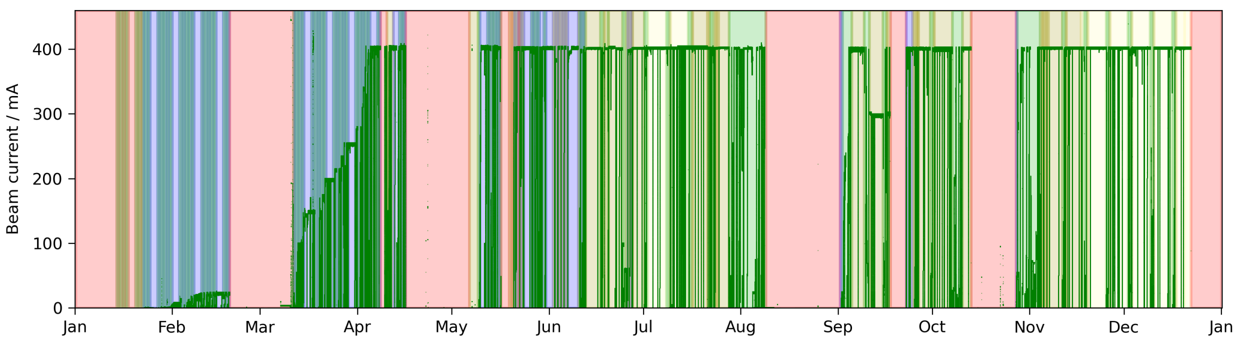

Figure 1: The SLS 2.0 beam current over the entire year 2025. The background colour indicates the scheduled operation mode, i.e., shutdown (red), machine commissioning/development (green), vacuum scrubbing (blue), beamline commissioning/development (olive) and user operation (light yellow).

Debye [3] and PXIII [4] both obtained their radiation permit within one day after taking first light on the 11th of April. During all first light shifts an active video call between the machine and respective beamline control rooms enabled quick realization of machine operation requests, e.g., applying orbit bumps at the beamline source points or changing the beam current, following the progress and requests of the beamlines. For every beamline the prerequisite for self-determined operation is successfully passing all required first light checks, i.e., passing the PSYS tests for their optics and experimental hutch; passing the individual function and the escalation test from the beamline experiment, FE and vacuum control systems to the machine protection system; getting first light along the design trajectory in the optics hutch; and obtaining the radiation protection permit, i.e., allowance for taking light without radiation protection officers present. The first insertion device (ID) beamline to obtain its radiation protection permit after successfully getting first light was ADDAMS [7] with their well-known CPMU14 ID from SLS-1, on the 21st of May. Overall, beamline commissioning progressed rapidly, with all beamlines securing their radiation protection permits as planned. Typically this could be achieved within one to two days, often even in parallel.

USER OPERATION

The first official user operation (see Fig. 2) of the SLS 2.0 was a two week pilot user operation in the first two weeks of July with two participating beamlines (ADDAMS [7], PXIII [4]) performing milestone experiments [8, 9]. Overall seven beamlines had by this time successfully completed their first light checks and were taking light during the pilot user operation period. A number of outages occurred during the second week due to a faulty ethernet connector at a beamline safety system.

The second and longer user operation period in 2025 (see Fig. 3) took place from mid November until 21st of December. During this user operation period overall 12 user beamlines were taking light. Out of these five (ADDAMS [7], PXIII [4], Debye [3], PolLux [10], SuperXAS [11]) were performing proposal review committee (PRC) [12] assigned user experiments.

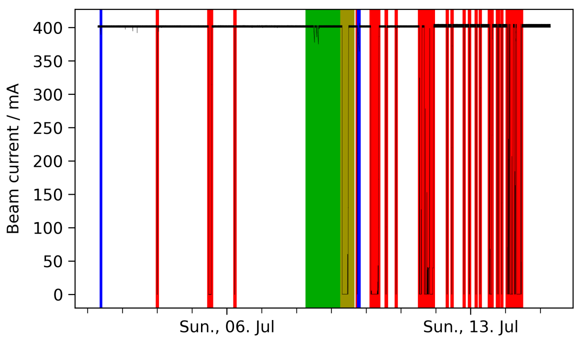

Figure 2: The delivered beam current during the first officially scheduled SLS 2.0 user operation period in the beginning of July with downtimes indicated in red, injector outages in blue, machine development shifts in green and beamline development in olive.

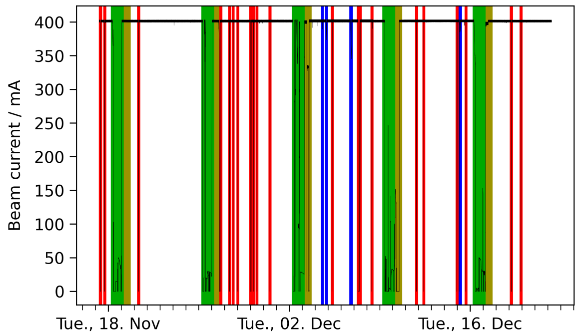

Figure 3: The delivered beam current from mid November until end of December during the first officially scheduled SLS 2.0 user operation period with PRC assigned beamline experiments.

OPERATION STATISTICS

The operation statistics for SLS 2.0 are calculated using the same metrics as was used for SLS-1 [13]. This consistency enables us to compare the statistics between SLS-1 and SLS 2.0 which presents a challenge since the SLS-1 delivered exceptionally good user statistics at the peak of its operation setting a high benchmark. Overall the machine schedule of 2025 is dominated by shutdown and machine or beamline commissioning time as shown in Fig. 4. After successful machine and beamline commissioning, the first two-week (pilot-) user operation period took place in the first half of July. Despite numerous beam interlocks caused by a faulty Ethernet connector in a beamline safety PLC, this initial period with 280 h of scheduled user time achieved an availability of 87.3 %, a mean time between failures of 10 h, and a mean time to recover of 1.3 h. Following the installation of additional IDs and further beamline com-

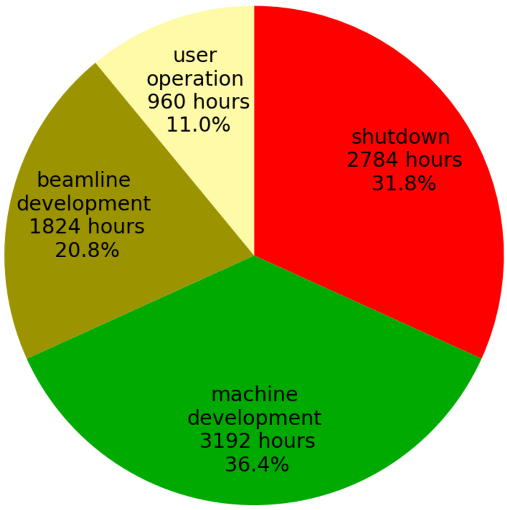

Figure 4: The SLS machine scheduling distribution for 2025.

Table 1: The SLS User Operation Statistics for 2025

	July	Nov./Dec.	Total
User Operation	280.0	680.0	960.0 hours
Downtime	35.5	18.6	54.1 hours
Downtime Outages	27.0	22.0	49.0
Injector Outage Time	0.8	2.9	3.7 hours
Injector Outages	2.0	5.0	7.0
Availability	87.3	97.3	94.4 %
with Compensation	–	–	99.3 %
MTBF	10.0	29.6	19.2 hours
MTTR	1.3	0.8	1.1 hours

missioning, the second user operation period in November and December delivered 680 h of scheduled user operation, with twelve beamlines cleared for taking light following first-light checks and radiation protection approval, including five supporting user operation and seven at various stages of commissioning, as well as two diagnostic beamlines. This period achieved an availability of 97.3 %, a mean time between failures of 29.6 h, and a mean time to recover of just 0.8 h. The operational statistics for all 960 h of 2025 user operation are summarized in Table 1. The 2025 overall availability of 99.3 % (including compensation) already matches the performance achieved in the final years of SLS-1. Some of the most significant challenges of 2025 are not directly reflected in the user-operation statistics, as they affected primarily machine and beamline commissioning time rather than scheduled user operation. The most persistent issue was vacuum conditioning after ID installation. A 2 m long dummy chamber without non-evaporable getter (NEG) coating with a 21 mm inner diameter in straight 11 produced a pressure bump that ultimately required the chamber to be removed and replaced. In addition, a 2 m long nitrogen-vented and NEG-coated vacuum chamber with a 9 mm inner diameter, for an elliptical, knot-type undulator (APPLE-X type) with period length 36 mm ID [14], also installed in straight 11, required substantially more vacuum scrubbing time than anticipated. These localized vacuum bumps led to reduced beam lifetime, increased beam size and increased radiation levels due to bremsstrahlung at these locations. Temporary reductions in beam current, and frequent radiation surveys were implemented to ensure safe beamline operation and prevent demagnetization of downstream permanent magnets. Because additional new IDs will be installed in the coming years, these experiences have prompted a revision of design, assembly, and installation procedures.

STATUS END OF 2025

Accelerator

At the end of 2025, the SLS 2.0 routinely achieves an injection efficiency into the storage ring exceeding 95 % and a beam lifetime greater than 12 h with 10 pm vertical emittance using vertical dispersion bumps and roughly 3-fold bunch lengthening from the superconducting third harmonic cavity (3HC). The fast orbit feedback (FOFB) system operates with a 400 Hz band width (BW), providing 140 nm RMS orbit stability in the horizontal and 90 nm RMS orbit stability in the vertical plane (integrated from 3 Hz to 3 kHz) [15, 16]. The filling pattern feedback (FPFB) successfully maintains the design filling pattern with a continuous bunch train of 450 out of 480 equally filled buckets [17]. Vertical beam-assisted girder alignment has been completed, achieving zero residual offset [18]. Vertical element-to-element alignment and horizontal girder alignment corrections for outliers and source points are still ongoing.

Beamlines

Two diagnostic beamlines are operational [19]. One uses the almost dispersion-free entrance of a 1.1 T homogeneous bending permanent magnet of the dispersion suppressor cell [20, 21] as a source point, while the other uses the low dispersion (5.8 mm) center of a 1.4 T homogeneous bending permanent magnet just like the regular dipole beamlines enabling meaurement of energy spread. Three bending magnet beamlines, i.e., PolLux [10], SuperXAS [11], and ISS [22], use the dispersion-minimized center of a 1.4 T homogeneous bending permanent magnet as a source point. Another three bending magnet beamlines, i.e., Debye [3], PXIII [4], and S-TOMCAT [23], utilize the dispersion-minimized center of a 2 T longitudinal gradient super-bending permanent magnet as a source point. Overall, six insertion device beamlines are taking light. Among these, two insertion device beamlines (I-TOMCAT/U15 [23, 24] and SIM/UE36kn [25]) are using new insertion devices designed for SLS 2.0 [26, 27], while four insertion device beamlines (ADDAMS/CPMU14 [7], PX-II/U19 [28], cSAXS/U19 [29], and PX-I/U19 [30]) were commissioned and are operating with well-established SLS-1 insertion devices.

SUMMARY

Overall, the commissioning of SLS 2.0 in 2025 has been highly successful. Nominal beam current was achieved ahead of schedule, and stable nominal operating conditions including more than 95 % injection efficiency, beam lifetimes above 12 h, and orbit stability of 140 nm RMS were reached in time for the second user operation period. These results demonstrate that SLS 2.0 has transitioned exceptionally rapidly from commissioning to reliable user operation at near-design performance, establishing a strong foundation for full-scale scientific exploitation.

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