

# SOLEIL 2025 OPERATIONAL STATUS

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## Abstract

SOLEIL, the French 2.75 GeV third-generation synchrotron light source, continues to operate as a high-performance research infrastructure serving both academic and industrial communities. This contribution reviews 2025 operational achievements, with an emphasis on accelerator stability, availability, and reliable photon-beam delivery to 29 beamlines. Key performance indicators and operational trends are presented, together with an analysis of major events and mitigation strategies implemented to improve machine robustness. Significant progress in addressing component obsolescence is reported, including advances in BPM electronics, RF systems, and the global control-system upgrade. Updates on the LINAC's modernization program are provided, along with the use of the SOLEIL accelerator as an integrated testbed to validate critical technologies for the forthcoming facility upgrade. Preparatory activities for SOLEIL II are outlined, including progress on the bunch-by-bunch transverse feedback system; development and preparation for qualification of new 352 MHz low-HOM RF cavities; the 1.4 GeV fourth-harmonic system; and upgraded control architectures, highlighting technical readiness for the next-generation machine.

## SOLEIL ACCELERATOR PERFORMANCE

SOLEIL is the French third-generation synchrotron light source that has provided highly stable, brilliant photon beams to external users since 2008 (see the main parameters in Table 1 [1]). Its injector complex is based on a 110 MeV LINAC and a full-energy 3 Hz booster ring.

Table 1: Basic Parameters of the SOLEIL Storage Ring

Parameter	Value
Circumference	354.097 m
Energy	2.75 GeV
Nominal Tunes (H/V)	18.146 / 10.216
Natural Chromaticities (H/V)	-53 / -19
Operation Chromaticities (H/V)	1.0 / 2.5
Momentum Compaction	$4.18 \times 10^{-4}$
RF Voltage	2.6 MV
RF Frequency	352.198 MHz
Harmonic Number	416
V/H Emittance Ratio	1 %
Total Lifetime (500 mA)	10 h

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In 2025, the 19th year of accelerator operation, 4873 hours of photon beams were delivered to SOLEIL's 29 beamlines out of 4947 scheduled hours, over 34 weeks. Four top-up filling patterns were used: uniform (71 %), hybrid (23.2 %), 1 bunch (2.9 %), and 8 bunches (2.9 %). Photon-beam availability reached 98.51 % over the year, with 20 weeks above 99 % and 9 weeks at 100 %. The mean time between failures was 97 h, while the mean time to recover was 1 h 26 min (Fig. 1). Despite this strong performance, operating the SOLEIL accelerator complex remains challenging, and failures (Fig. 2) inevitably affect operation; several are summarized below.

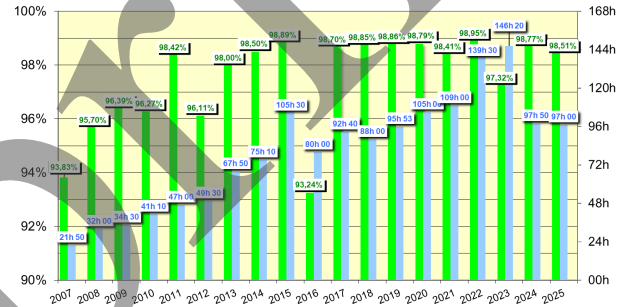


Figure 1: Beam availability (green) and mean time between failures (blue) over the years.

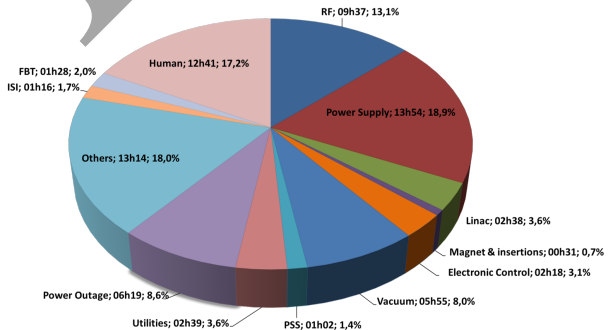


Figure 2: Distribution of beam failures per origin.

## Major Incidents

During the first run of 2025, operation was severely challenged by strong degassing in the newly installed CPMU18 undulator, which led to electron-beam excitation driven by local pressure spikes. While a temporary working point was identified to maintain a maximum current of 500 mA, it required numerous titanium sublimation pump firings to lower

the pressure and minimize bremsstrahlung radiation on the CRISTAL beamline. To address these issues, a thorough inspection was conducted during the February technical shutdown. It confirmed that overheating and outgassing were indeed real, as evidenced by significant carbon deposits, temperatures exceeding 180 °C, and a distinct top/bottom asymmetry on the downstream transition. To resolve this thermal contact problem, the top Cu sheet was replaced, and extra PT100 probes were added to improve the characterization of future overheating. Furthermore, an additional ion pump was installed to increase local pumping capacity. Following these structural modifications and the addition of the vacuum pump, the local pressure was successfully reduced. This ensures that the strict bremsstrahlung radiation safety thresholds required to open the beamline shutter are fully met, even at the minimum undulator gap of 5.5 mm.

The longest beam interruption of the year (11 h 02 min) was caused by a failure of the LINAC-to-Booster transfer-line dipole power supply, which stopped top-up injection, and was followed 1 h 30 min later by a beam loss due to excitation during beam decay. The failure was difficult to diagnose because a (now corrected) misconception initially pointed to an unrelated issue. A new dipole-control rack is under construction and will be installed in summer 2026.

Another long beam stop (7 h 58 min) resulted from two factors. First, an emergency cable was cut in the T3 building during rehabilitation work — which had previously housed the cooling station —. The issue was resolved within one hour, but it impacted the storage-ring RF cavity system long enough to require a full restart of the cryogenic system. This second phase typically takes up to eight hours, but it was accelerated by effective operational maneuvers from the on-site cryogenics team.

Then a fire started in one of the RF tower amplifiers used for the storage-ring RF cavities (Fig. 3). Thanks to the rapid response of the on-duty operator and the security guard in the control room, the fire was quickly brought under control. After clearance by firefighters and SOLEIL security personnel, the beam was restored after a 2 h 13 min interruption, using 3 of 4 SSPA amplifiers to feed the RF cavities. Subsequent investigations revealed that the issue was a cable fire in an RF SSPA tower of the second RF cavity, triggered by a loose connection on at least three cables on a combiner. As an immediate solution, the RF group tightened all cables across the system. The tower was subsequently refurbished by the RF group and recommissioned a few weeks later (installation of fireproof insulation around the cables).

Two days before the summer shutdown, at 2:00 a.m., a significant water leak was discovered in one of the two LINAC's klystrons reducing the output electron energy from 110 MeV to 66 MeV. In this configuration, beam was injected into the Booster after retuning the LINAC, the transfer line, and the Booster. This approach enabled beam recovery in 2 h 36 min.



Figure 3: RF tower amplifiers just after fire control.

## MAJOR DEVELOPMENTS AND ACHIEVEMENTS

The SOLEIL injectors and accelerators continue to serve as a testbed for SOLEIL II, through the testing of future equipment and the refurbishment of existing devices, while maintaining maximum compatibility with the future accelerators.

Preliminary work is underway for the LINAC's energy upgrade (from 110 MeV to 150 MeV), scheduled for the summer 2026 technical shutdown. This includes hardware upgrades (power supplies, new beam stoppers, radiation monitors) and a new control architecture fully compliant with SOLEIL II, comprising the replacement of CPCI chassis with PLCs and the upgrade of magnet equipment-protection systems. A spare buncher manufactured by THALES AVS will be installed in early 2027 to recover high-gradient performance (targeting 15 MeV versus the current 12 MeV) and to ensure spare-part availability. In addition, JEMA Energy delivered a first SSPA-based modulator in 2024 to preserve the nominal beam energy and avoid the downgrade to 66 MeV that currently occurs in the event of a klystron failure.

A prototype of future BPM electrodes has been installed in a straight section of the storage ring. Two sets of 12 feedthroughs, supplied by two manufacturers, were welded onto a dedicated vacuum chamber. The BPM buttons are located 8 mm from the beam axis, consistent with the SOLEIL II BPM aperture. These tests validated the feedthrough design, in particular the conical button shape. For the BPM electronics, the commercial Libera Brilliance+ solution was selected. To meet SOLEIL II specifications, several adaptations were implemented by the manufacturer: a higher switching frequency, a new low-latency fast-data stream, and beam-angle and beam-radius interlock functionality.

The 220 modules were delivered at the end of 2025, followed by site acceptance tests. Since January 2026, one full storage-ring cell (7 BPMs) has been equipped with the new electronics, fully integrated into the orbit feedback and machine-protection systems. Replacement of the electronics for the entire storage ring is planned for summer 2026.

A new cryogenic undulator (CPMU18 [2, 3]) — the third of its kind — was installed on the CRISTAL beamline, replacing the original U20 in-vacuum undulator. This upgrade enhanced both flux and brilliance while extending the accessible photon-energy range: brilliance gains reach a factor of 1.4–2.6 at 8 keV to 10 keV and a factor of 8 at 45 keV (Fig. 4).

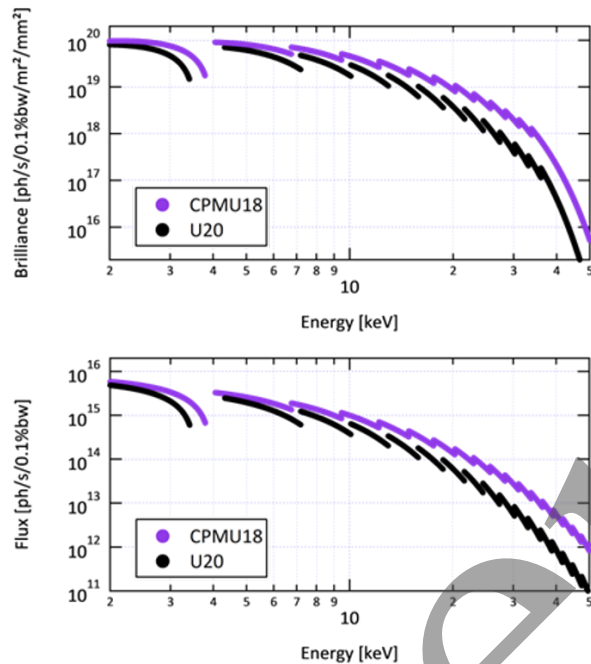


Figure 4: Comparison of brilliance (top) and flux (bottom) against photon energy between the old U20 undulator and the new CPMU18 one installed on CRISTAL beamline.

The transverse bunch-by-bunch feedback (TFB) system is undergoing a major software architecture upgrade using Python, yielding significant improvements in data-processing performance and expanding the diagnostic tools available for beam-instability analysis. In the near future, this will also reduce the tune measurement time for a single bunch by a factor of ten. A new suite of automated scripts has already been deployed to excite the beam across multiple frequencies and measure the subsequent damping time. For SOLEIL II [4–6], the TFB system will be based on the Diamond DLS-MBF digital signal processor, already in operation at five European light sources. Transverse instability damping times of 20–50 turns have been measured on the present SOLEIL ring with this system, well within the SOLEIL II requirements [7, 8].

A longitudinal bunch-by-bunch feedback system (LFB) [9] is in development; a proof-of-concept experiment was carried out in summer 2025. The LFB kicker cavity design is based on the Frascati cavity type. A Hamamatsu

streak camera delivered in March 2026 will serve as the primary longitudinal beam-profile diagnostic.

As part of the equipment rejuvenation program for systems that will continue in service under SOLEIL II—and to reduce fire risk—the storage-ring RF amplifier towers are being progressively modernized. Since early 2024, a new 50 kW tower has been installed every two to three months during each shutdown. This steady upgrade program will be completed by mid-2027, at which point the facility will have four fully upgraded 200 kW solid-state power amplifiers (SSPAs). Beyond the marked improvement in reliability and controllability, this major refurbishment will deliver substantial energy savings of 1.75 GWh per year.

SOLEIL II will require a large number of temperature sensors to prevent machine damage, and the resulting channel count is incompatible with the available trench-cable capacity. A new acquisition system is therefore planned for the storage ring, aggregating multiple measurements locally and transmitting data over a limited number of Ethernet links. A prototype has been installed beneath one of the current storage-ring dipoles to evaluate its robustness in the radiation environment.

A multi-year RF modernization roadmap is underway to transition the SOLEIL storage ring toward its upgraded configuration. During the summer 2027 shutdown, one of the existing cryogenic RF cavities will be decommissioned and replaced by two 352 MHz normal-conducting, higher-order-mode (HOM) damped cavities (ESRF-EBS type) built by Research Instruments GmbH. The first two cavities (out of five) are scheduled for delivery in October 2026, followed by an intensive high-power RF conditioning campaign starting in December 2026. This requires substantial infrastructure preparation in early 2027: expansion of the RF support frame, modification of the RF bunker, and construction of a dedicated test facility on the LINAC’s roof. This test area will subsequently support the conditioning of three additional 352 MHz HOM cavities—featuring 250 kW fundamental power couplers developed in collaboration with CERN based on an APS design—to be delivered by fall 2027. The same infrastructure will also be used to validate the upcoming 1.41 GHz harmonic cavity system planned for 2028, consisting of two operational cavities and one spare.

A home-made digital low-level RF (prototype has been fully developed, with an analog front-end designed in collaboration with CEA. The fast interlock functionality has been successfully validated and the system has been undergoing beam tests in a booster cavity since February 2026, entering routine booster operation on April 2026. Initial tests in a SOLEIL storage-ring cavity with stored beam were fully successful, achieving closed-loop regulation accuracies of  $3 \times 10^{-4}$  in amplitude and  $2.4 \times 10^{-2^\circ}$  rms in phase. The next steps focus on implementing a dedicated conditioning function to ensure system readiness for high-power coupler and cavity tests by winter 2026, followed by series production and installation of two systems on the SOLEIL storage ring from early 2027.

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