STATUS OF SIRIUS OPERATION

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Abstract

SIRIUS is a state-of-the-art synchrotron light source facility, featuring a 3 GeV electron storage ring with a 518 m circumference and 250 pm rad emittance. Built and operated by the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas, Brazil, SIRIUS has undergone significant upgrades over the past year. These include the installation of a cryogenic plant, superconducting RF cavities, in-vacuum undulators, and new orbit feedforward systems, among others. This report summarizes these developments, highlights improvements in beam stability, and provides an overview of the facility's operational status over the past year.

INTRODUCTION

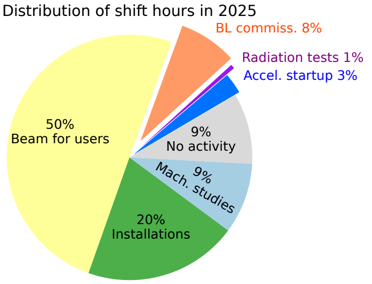
SIRIUS is the Brazilian synchrotron light facility that has been in operation and open to external users since March 2023. The design and construction of this green-field fourth generation light source began in 2012, and now in 2025, the facility has matured into a fully operational research center serving national and international scientific communities.

As of 2025, SIRIUS Phase-I comprises 14 beamlines (BLs), with 10 fully available to users, 3 being commissioned, and 1 under construction. These include 8 undulator-based BLs, 3 utilizing low-field dipoles, and 3 using superbend dipole sources. Phase-II(A) scheduled for completion in 2027, will add 4 BLs: two undulator-based, one from a low-field dipole, and one from a high-field dipole source. Future phases are projected to include 7 additional BLs [1].

In 2024, the opening of additional BLs and an extended operational period led to a significant increase in research proposals. In total, SIRIUS supported 309 research proposals in 2024, benefiting 1,140 external researchers from 187 Brazilian and international institutions. Despite a long shutdown in the second half of the year for, among other activities, the installation of 2 superconducting RF cavities and 2 in-vacuum insertion devices, SIRIUS exceeded previous years' numbers by 38% in users and 22% in proposals. Preliminary 2025 data indicate further growth, with over 350 proposals supported via the fifth and sixth regular calls.

Operation Performance and Reliability

Throughout 2024, SIRIUS maintained a high level of activity, with 45% of the total accelerator operation hours dedicated to beam time for users at the BLs. Additionally, typical machine time was allocated to installation-related activities and machine studies. Starting in November 2024, SIRIUS shifted from a 24/6 to a continuous 24/7 schedule by including Sundays, significantly reducing the fraction of no-activity shifts and further expanding its capacity to serve the scientific community. The distribution of machine shift hours for 2025 reflects this continued increase in beam time for users compared to previous years, while maintaining necessary time for installations and machine studies (Fig.1).



Shift hours	2025	2024
Beam for users	4392	3936
Installations	1776	1728
Mach. studies	816	864
No activity	816	1536
Accel. startup	240	480
Radiation tests	48	48
BL commiss.	672	144

Figure 1: Distribution of machine shift hours.

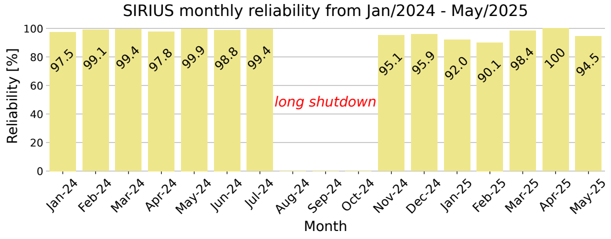


Figure 2: Monthly SIRIUS reliability data since January 2024.

SIRIUS demonstrated high operational reliability in 2024, achieving 98.1% uptime over 3,936 scheduled beam delivery hours. Despite 14 beam trips during this period, the system showed robustness with a Mean Time Between Failures (MTBF) of 105.3 hours and a Mean Time To Recovery (MTTR) of 1.2 hours. Monthly performance metrics showed consistency throughout the year. The MTBF showed greater variation, with a significant peak in March, indicating a lower frequency of failures, while the MTTR remained low and stable, ensuring rapid resumption of activities after any interruptions (Fig.2).

SIRIUS STORAGE RING

The SIRIUS storage ring, previously detailed in [2–4], operates at 3 GeV with a 518 m circumference and achieves a bare lattice emittance of 250 pm rad. The ring's twenty 5BA achromatic cells support approximately 40 beamlines originating from three source types: 18 from 6.5 m long straight sections housing insertion devices (IDs), 20 from 3.2 T superbends, and up to 10 from 0.6 T dipole sources.

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These cover a photon energy range from infrared to hard X-rays. The 5-fold symmetric lattice features two distinct straight section types: 5 high-beta sections and 15 low-beta sections with 1.5 m betatron function in both planes at their center to optimize brightness by matching electron and photon phase spaces and allowing narrow-gap insertion devices with minimal optics perturbation. For a detailed analysis of effects of the latest IDs, see [5].

As of November 2024, the storage ring operates with a beam current of 200 mA in *top-up mode* with 1-minute injection intervals at whole minutes. At this current, the beam lifetime, dominated by Touschek scattering, is approximately 8 hours for the standard optics configuration of a 2% transverse emittance ratio. This lifetime and limitations of the single-shot injector (detailed below) demanded a shorter top-up interval of 1 minute; previously, with a 100 mA beam current, injection occurred every 3 minutes. This more frequent injection remains compatible with beamline operations, as *injection transparency* has reached a level where its impact on users experiments is negligible.

Improvements resulted from systematic enhancements of the non-linear injection kicker (NLK) and the implementation of *orbit feedforward loops* to compensate for septa leak fields. The NLK enhancements included additional correction coils, pulse format changes, and realignment to reduce stored beam perturbation. Four fast correctors, deployed in the injection straight section to address septa leak fields affecting the stored beam orbit, use power supplies running excitation current waveforms synchronized with each injection. Additionally, the slow orbit feedback loop (SOFB) was adapted to implement feedforward waveforms in corrector power supplies, mitigating 2 Hz booster energy ramping perturbations. The SOFB now corrects slow orbit drift by adjusting these feedforward waveform offsets. Complementing this, the fast orbit feedback system (FOFB) (operating at 48 kHz update rate, 1 kHz crossover frequency [6,7]) effectively damps residual beam oscillations from injections. To further enhance injection transparency, ongoing developments include a new ceramic chamber for the NLK [8] with an inner titanium thin coating — developed in collaboration with ALBA — aimed at reducing induced image currents, and the implementation of new feedforward (FF) power supplies for the septa featuring a wider response bandwidth.

Preliminary experiments in late 2024 demonstrated operation up to at least 250 mA with the current installed RF power, without overheating vacuum chamber components due to broadband impedances. Operating top-up with *increased beam current* over 200 mA is a possibility, contingent on injector improvements. Reaching the Phase-II target of 350 mA requires a *harmonic cavity* to elongate the longitudinal beam size, serving two purposes: to mitigate component overheating by shifting the beam frequency spectrum away from chamber impedances, and to achieve the design lifetime required for designed radiation protection. Recently, a passive third-harmonic superconducting cavity (3HC) for SIRIUS was specified. Procurement for a 3HC-SINAP 2-cell model cavity [9] is being finalized, with an expected delivery by SARI-CAS [10] of 18 months.

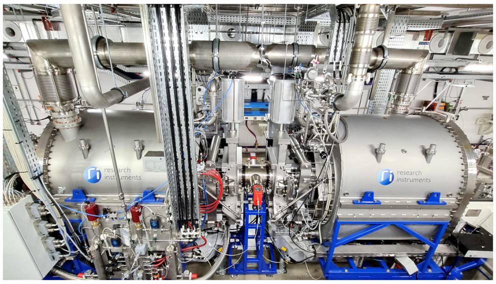

Figure 3: SRFCavs after installation in the storage ring. The cavities were installed back-to-back so that they would fit in a single straight section.

Prior to the mid-2024 RF upgrade, higher-order modes (HOMs) from the former PETRA 7-cell cavity drove longitudinal coupled-bunch instabilities (LCBIs) around 80 mA. A Dimtel [11] bunch-by-bunch (BbB) feedback system controlled these instabilities. Following the installation of the *new superconducting RF cavities* (SRFCavs), different LCBIs persisted, appearing at currents as low as 90 mA. Recent studies investigated the likely sources of these new instabilities and show that with the 3HC the longitudinal BbB system will not be needed for beam stabilization [12,13]. SIRIUS employs Dimtel BbB systems in the transverse planes as well, although the corresponding instabilities have not yet been fully characterized.

Installation of *high-performance insertion devices* (IDs) began in November 2023, replacing commissioning IDs. To prevent potential damage to vacuum chamber components caused by high-power radiation from these IDs, in case of steering errors in the electron beam orbit, a *fast beam orbit interlock system* (FBOIS) was designed and implemented. The FBOIS utilizes a dedicated real-time position and angle calculation within an FPGA, operating at 6 kHz in the processing electronics of beam position monitors (BPMs) near the ID. A timing receiver board in the BPMs' MicroTCA.4 crate links orbit distortion detection to the timing system's event generator, which then sends an interlock signal to the low-level radio frequency (LLRF) controller to cut off main RF power [14]. Currently, four FBOIS systems are operational in the storage ring, with a fifth scheduled for addition in July 2025 alongside another ID installation.

SRF Main Cavities and Cryogenic Plant

In mid-2024, two CESR-B SRFCavs were installed back-to-back in a single straight section to replace the normal-conducting PETRA 7-cell cavity in SIRIUS' storage ring, enabling beam current to reach beyond 100 mA for users (Fig.3). Additionally, two 65 kW solid-state amplifiers (SSAs) and a low-level RF (LLRF) system were assembled for the RF plant, with each SRFCav fed by two SSAs and controlled independently.

RF conditioning of both SRFCavs took approximately one week. It began in pulsed mode (1.25% duty cycle), with the gap voltage increased toward 2 MV as vacuum pressure permitted. Once 2 MV was reached, the duty cycle was progressively increased to achieve continuous wave (CW) operation. The RF window underwent similar conditioning, reaching 100 kW. An LLRF-based quench detection interlock protected the cavities during this process.

While the original Phase-II RF system plan is detailed in [15], the addition of a third SRFCav, powered similarly by two 65 kW SSAs, is under consideration for strategic advantages. This third cavity would provide redundancy for uninterrupted operation should one cavity fail, albeit with a slightly lower beam current than the target 350 mA.

The cryogenic plant, essential for the SRF cavities and future 3HC, was supplied by Linde Kryotechnik AG [16]. Project completion occured in February 2022, followed by manufacturing throughout 2022-2023. Commencing operation in March 2024, the plant has run for approximately 15 months as of mid-2025, including 8 months supporting the SRFCavs. It is located directly above the accelerator tunnel section housing the RF cavities (Fig. 4). It is monitored and controlled 24/7 from a dedicated control room by recently trained staff with no prior experience in cryogenics.

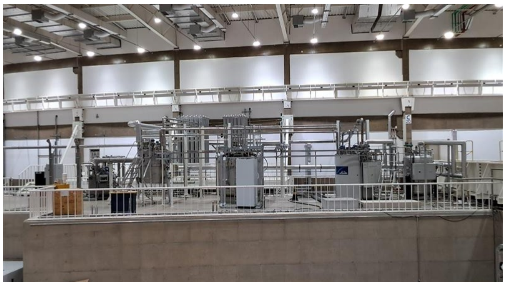

Figure 4: Cryogenic plant located above the accelerator tunnel near the RF cavities.

The helium cryogenic plant has a design capacity of 750 W at 4.5 K, and the estimated current heat load for the target configuration (three main SRFCavs, one 3HC) is 429 W, leaving a substantial 321 W margin (approximately 75% of the current load) for future needs or contingencies. Foreign material contamination, recently observed in the cold box, impacted plant efficiency. A partial plant warm-up mitigated the issue. The contamination source remains under investigation. A full warm-up, planned for 2026, is expected to fully resolve the issue.

Injector Pending Issues

There are a few pending issues with the injector that currently prevent SIRIUS from operating with beam currents above 200 mA. The most severe is significant heating of the septa and underlying vacuum chambers when pulsing. Injection efficiency, especially in the booster, drops considerably with a second pulse at 2 Hz. This effect limits SIRIUS to single-shot injections for top-up. As for full accumulation, today it is done with shots at 3-second intervals to prevent injection efficiencies from dropping drastically. Figure 5 shows an example of recorded temperature rises of various septa chambers during a full accumulation to 100 mA, before top-up was implemented and when the injector parameters were set to ”a hot septa configuration”. This increase in temperatures is due to spurious low-impedance secondary current loops [17], which have been measured in situ. In addition, bench tests show the impact of these loops on temperatures and magnetic field pulse-to-pulse variations. Electrical isolation improvements to the booster septum supporting structure is underway at this moment.

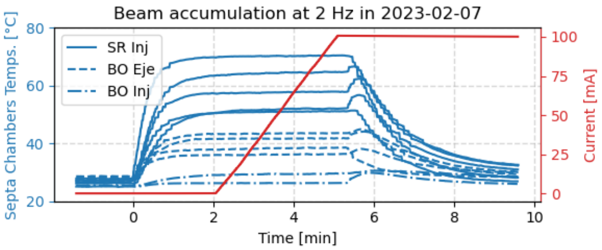

Figure 5: Temperature increase in septa chambers during a full accumulation to 100 mA at 2 Hz with injector priot set to a ”hot septa” configuration.

Another issue concerns beam injection in the booster, where a large fraction of the charge is lost within the first hundred turns after injection. Losses are typically around 40% for top-up, or 20% after optimization during machine studies. The cause is believed to be an optics mismatch in the linac-booster transport line, probably due to septum field distortions induced by the secondary loops mentioned before. The beam charge that survives and is ramped in the booster varies considerably from injection to injection. Efforts are underway to better characterize the linac beam using phase-space tomography reconstruction from images acquired with YAG screens [18].

Although the booster optics is routinely optimized throughout the energy ramp, an invariant horizontal orbit bump remains. It currently cannot be corrected, as its signature falls within the null space of the orbit response matrix. This issue was recently investigated, and a possible fix has been proposed and is under consideration [19].

CONCLUSIONS

Operation in top-up mode at 200 mA has been successfully established and remains stable. Four new high-performance IDs were installed, enhancing the spectral capabilities of key beamlines. Combined with the installation of the SCRF cavities, these developments significantly advanced the facility’s performance and reliability. The transition to continuous 24/7 operation and the growing number of beamlines have driven a substantial increase in user demand and scientific output. With injector upgrades underway, harmonic cavity procurement in progress, and ongoing progress in beam dynamics and feedback systems, SIRIUS is well-positioned to reach Phase-II goals.

REFERENCES

[1] “SIRIUS Annual Report, 2024”, `https://cnpem.br/relatorios-de-2024/`.

[2] L. Liu *et al.*, “Upgraded optics for SIRIUS with improved matching of electrons and photons beam emittances”, Proc. *IPAC’15*, Richmond, VA, USA, May 2015, pp. 1407-1409. `doi:10.18429/JACoW-IPAC2015-TUPWA007`

[3] L. Liu and H. Westfahl Jr, “Towards diffraction limited storage ring based light sources”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper TUXA1, pp. 1203-1208. `doi:10.18429/JACoW-IPAC2017-TUXA1`

[4] L. Liu *et al.*, “Status of SIRIUS operation with users”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 2586–2589. `doi:10.18429/JACoW-IPAC2023-WEOGA2`

[5] G. Ascenção, M. Alves, L. Liu, and X. Resende, “Study of insertion devices effects in SIRIUS”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 1184–1187. `doi:10.18429/JACoW-IPAC2023-MOPM088`

[6] D.O. Tavares *et al.* “Commissioning and Optimization of the SIRIUS Fast Orbit Feedback”, in *Proc. ICALEPCS’23*, Cape Town, South Africa, Oct. 2023, pp. 123–130. `doi:10.18429/JACoW-ICALEPCS2023-MO3AO03`

[7] L. Pelike *et al.*, “Modeling of the SIRIUS fast orbit feedback control loop”, in *Proc. Proc. IBIC2024*, Beijing, Sep. 2024, pp. 241-244. `doi:10.18429/JACoW-IBIC2024-WECC2`

[8] R. Defavari *et al.*, “Manufacturing of Ceramic Vacuum Chambers for Sirius On-Axis Kicker”, presented at the 12th Int. Particle Accelerator Conf. (IPAC’21), Campinas, Brazil, May 2021, paper TUPAB400. `doi:10.18429/JACoW-IPAC2021-TUPAB400`

[9] Y. Zhou *et al.*, “Experimental verification and analysis of the beam loading effect based on precise bunch-by-bunch 3d position measurement”, *Nucl. Instrum. Methods Phys. Res. A*, vol. 1051, p. 168201, Jun. 2023. `doi:10.1016/j.nima.2023.168201`

[10] SARI-CAS, Shanghai Advanced Research Institute, Chinese Academy of Sciences, `http://english.sari.cas.cn`

[11] Dimtel iGp12 bunch-by-bunch processor unit, `https://www.dimtel.com/products/igp12`

[12] M. Barbosa Alves, “Longitudinal collective effects in synchrotrons with double-rf system”, Ph.D. dissertation, Universidade Estadual de Campinas, Campinas, Brazil, 2025.

[13] M. Alves and F. de Sá, “Beam-based characterization of longitudinal coupled-bunch instabilities at SIRIUS storage ring”, presented at the IPAC’25, Taipei, Taiwan, Jun. 2025, paper WEPM104, this conference.

[14] L. Perissinotto *et al.*, “SIRIUS fast beam orbit interlock system”, in *Proc. Proc. IBIC2024*, Beijing, Sep. 2024, pp. 546-549. `doi:10.18429/JACoW-IBIC2024-THP29`

[15] A. P. B. Lima, I. Carvalho de Almeida, D. Daminelli, R. H. A. Farias, M. Hoffmann Wallner, and F. K. G. Hoshino, “Sirius Storage Ring RF System Status Update”, in *Proc. IPAC’22*, Bangkok, Thailand, Jun. 2022, pp. 872–875. `doi:10.18429/JACoW-IPAC2022-TUPOST014`

[16] Linde Kryotechnik AG, `https://www.linde-kryotechnik.ch`

[17] O. Dressler, M. V. Hartrott, and N. Hauge, “Determination of the Magnetic Characteristics in the Injection Septum for the Metrology Light Source”, in *Proc. IPAC’10*, Kyoto, Japan, May 2010, paper TUPEC026, pp. 1773–1775.

[18] O. Silveira and F. de Sá, “MENT algorithm for transverse phase space reconstruction at SIRIUS”, presented at the IPAC’25, Taipei, Taiwan, Jun. 2025, paper THPM035, this conference.

F. de Sá and O. Silveira, “Studies on the large residual horizontal orbit in the SIRIUS booster”, presented at the IPAC’25, Taipei, Taiwan, Jun. 2025, paper WEPM103, this conference.