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THE CONTROLS AND SCIENCE IT PROJECT FOR THE SLS 2.0 UPGRADE

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Abstract

On the 30th of September 2023 the dark time for the Swiss Light Source (SLS) facility began. SLS 2.0, a project to upgrade the storage ring and selected beamlines now enters the construction phase. With the advent of the next generation of synchrotron light sources, called diffraction-limited storage-rings (DLSRs), that yield an emittance and brightness improved by up to two orders of magnitude, it has become equally imperative to upgrade the SLS to accommodate the new developments. The storage ring is undergoing its upgrade in 2023/2024 with a planned reduction of emittance by a factor of 40, before the facility returns to user operations in 2025.

INTRODUCTION

The SLS [1] (Fig. 1), operational since 2001, has remained one of the leading examples of third-generation storage-ring technology for two decades. However, the increasing scope and impact of the uses of synchrotron light sources in almost all areas of the natural and engineering sciences, improvements in source and instrument technology generally, and the advent of diffraction-limited storage-rings (DLSRs), highlighted that the SLS would benefit from undergoing a comprehensive upgrade to remain competitive and perform cutting-edge science [2].

Figure 1: The main entry to the SLS building on the morning of the 30th of September 2023, just prior to dark time.

The SLS 2.0 upgrade project will provide a significant increase in brightness by replacing the current magnet lattice of the storage ring by a new multi-bend achromat (MBA) magnet structure. This, combined with advanced hardware and instrumentation, will enhance the performance of all techniques currently practiced at the SLS by up to three to four orders of magnitude in some cases, while heralding, on the one hand, new and game-changing sources and, on the other, new and innovative techniques.

Table 1: Main SLS Specifications after SLS 2.0 Upgrade

Parameter	Value
Circumference	288m
Total straight length	~80m
Beam current	400mA
Source point position [shifts]	< 70mm
Lattice type	7 bend achromat
Emittance	157pm
Energy	2.7 GeV

The upgrade focuses on the transformation of the storage ring lattice to MBA technology and the upgrade of the selected beamlines and end-stations to take full advantage of the increased brightness of the machine (Table 1).

The accelerator upgrade will incorporate new technologies in the SLS, such as superconducting magnets, which will extend the X-ray spectra to higher energies. In addition, permanent magnet material will be used for many of the ambient temperature magnets, resulting in an important reduction in power consumption. A crucial feature for the MBA design is a significant reduction in the vacuum chamber cross-section, achieved thanks to the use of a non-evaporable getter coating on the chamber surface. One truly original feature of the new lattice is the use of "reverse-bend" magnets, which play an important role in the brightness increase. The schedule for the upgrade and its key milestones are in Table 2.

Table 2: SLS 2.0 upgrade timetable. (*a total budget of 130MCHF and ~4% for controls and IT, excluding existing staff resources.)

	Milestone	Date
1	Definition of ring lattice	30/06/2020
2	Beamline and positions defined	30/09/2020
3	SLS 2.0 funding secured*	01/01/2021
4	Ready for dark time	17/10/2022
5	Start of dark time	30/09/2023
6	Tunnel closure	20/12/2024
7	First beam available	01/05/2025
8	Start of user operation on first beamlines	01/08/2025
9	Start of shutdown phase 2	21/12/2025
10	Re-start user operation	01/06/2026

The upgrades of the accelerator and the beamlines and PSI's leading role in the development of complementary technology (e.g. insertion-device design, x-ray detectors,

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x-ray optics) will yield unique research opportunities especially in imaging, diffraction, and spectroscopy, areas in which SLS presently is a leading player.

CONTROLS AND SCIENCE IT

As with other peer facilities, research at SLS has invariably become underpinned by computing and IT capabilities. The control system and the IT environment of large science facilities is a central and vital part to ensure operation and scientific success. Recognising the importance and role of the area for the SLS 2.0 upgrade, in 2021, Controls and Science IT (CaSIT) was established as one of the four subprojects that form the SLS 2.0 project.

The other three project being namely:

- Infrastructure and Logistics
- Storage Ring
- Photon Science

The key goals for CaSIT are to facilitate standardisation, exploit new technical advances, challenge and revisit existing approaches, refine concepts where needed, to facilitate improved development cycles and software quality as well as strengthening the exchange between accelerator and beamlines. A comprehensive conceptual design report was published after review in 2021 [3, 4].

With a potential for data to be produced at over 40 GB/s [5] and eventually predicted to exceed 30 PB/year, one of the key challenges for CaSIT will be meeting the demands to accurately control beamlines along with capturing, reducing and analysing data from the beamlines. The multidisciplinary CaSIT group is aiming to exploit the best innovative technologies from academia and industry while ensuring a long-term legacy for simplified support and compatibility. These activities vary from advances in low level electronics and motion controls to ensuring the best environment for beamline experiment control and exploiting new technology advances in artificial intelligence and machine learning. The requirement for long term data preservation and publication through open research data initiatives is also considered as a core activity.

Accelerator and Beamline Control System

In addition to the general requirements mentioned above, the SLS 2.0 project faces the task of integrating a new generation of control systems with old legacy systems, as the LINAC and the booster ring will not be upgraded with the storage ring. The same applies for some beamlines that postponed their upgrades due to the prioritisation of high impact beamlines [6]. To bring the legacy systems into a status that will enable the continued usage, software upgrades were prepared and tested before the dark time started. For example, support for VxWorks-6 operating system was developed for MVME23xx Motorola boards to enable them to use the NFS version 3 mounting.

The controls system will continue using the EPICS toolkit [7] more specifically the EPICS version 7. Legacy systems have already been upgraded to run EPICS version 7 to ensure best compatibility and easy upgradability. Due to resource limitations, the SLS 2.0 upgrade project has limited the use of EPICS 7 to the well-known channel access protocol for the commissioning time.

The hardware solutions used for the control system will not use a costly "one-size-fits-all" approach but a developed toolbox strategy. This requires most solutions to be selected primarily from a predefined list (see Table 3). The bus standard for high-end requirements is Compact PCI-Serial (CPCI-S), which was selected after a review as the successor to the old VME standard.

Table 3: Overview of the Control System Hardware Toolbox

Hardware Solution	Use Case
CPCI-S Toolbox	Fast ADC/DAC or DIO Signals, if needed with specific FPGA (Field Programmable Gate Array) Development. An example are the LLRF Systems
Embedded systems (Zynq UltraScale+)	Special developments for PSI where CPCI-Serial or a commercial solution does not fit the requirements. An example is the DBPM3 system.
network/ serial devices	Commercial devices that come with a network (preferred) or serial interface. Examples are vacuum gauges, temperature controller, oscilloscopes, and PLC systems.
ECMC based on Beckhoff and Servers	Default for all motion systems at the accelerator and the beamlines. Simple and slow signals that can be read out through Beckhoff systems without need of PLC logic

The timing and event system will be realised according to the standards provided by Micro-Research Finland. While the original SLS was equipped with an all-VME system, the new system will have several possibilities to receive events: embedded solutions based on FPGAs, CPCI-S cards, and legacy VME EVR cards.

Motion control is predominantly a beamline concern as only few systems in the accelerator (like girder movers) need motors. All new installations in both accelerator and beamlines will be based on the EtherCAT bus systems and motor drivers provided by the company Beckhoff. The ECMC (EtherCAT Motion Controller) module for EPICS developed by the European Spallation Source is used as the bus master running on a PC or server [8].

Beamline Experiment Control and Data Handling

Beamline experiment control on SLS beamlines after the SLS 2.0 upgrade will be via BEC (Beamline Experiment Control), an extension to the BlueSky [9] software suite. The BEC software will utilise the Ophyd component of BlueSky and extend the suite to a full microservice architecture based around Redis [10]. The services will predominantly run on a virtualised platform operated and supported by PSI's central IT group [3]. Multiple layers of graphical user interfaces for the ecosystem are being investigated but one is likely to be based on pyDM (Qt). See

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Wakonig et. al for [11] more details. Remote access will be available through a remote desktop application currently NoMachine [12] and native web-based interfaces are also under investigation. Users will be individually identified with a personal PSI username authorised through active directory and authenticated with multi factor authentication.

Data from the beamlines will be streamed and stored on an IBM Storage Scale (formerly GPFS) file system in NeXuS [13] files located in a data centre over 300m away from the synchrotron facility. The total throughput and storage available is currently under negotiation with vendors but is expected to be in the region of 60 GB/s and a maximum of 15 PB respectively. Quotas associated with each beamline will be used to allocate storage usage. At least 5,000 CPU cores and 25 GPUs will initially be available for online data processing and analysis. Long term data storage and archiving in accordance with the PSI Data policy [14] is achieved in conjunction with the Swiss National Supercomputer Centre (CSCS) in Lugano, southern Switzerland, which has two dedicated 100 Gb/s fibres connecting them to PSI.

Data reduction, processing and analysis workflows in PSI are developed predominantly by instrument scientists who work closely with software engineers to maximise the usage of the infrastructure, deployment and stable operations services.

Edge computing to process data in memory being read out by the highest rate detectors is being exploited and reported elsewhere [15]. An initiative with CSCS for on demand peak or high load processing resources was started in 2019 with a Swissuniversities project known as SELVEDAS [16] which has now been superseded by the SwissTwins collaboration [17].

The SciCat data catalogue, hosted on a commercial cloud platform, is already in extensive use at PSI as reported in Minotti et al [18]. An electronic laboratory notebook (ELN), SciLog, is also available for PSI researchers [19].

Underpinning Network Services

The SLS 2.0 will upgrade networking to accommodate the anticipated increased network demands. The core network will be 100Gb/s. The machine network will accordingly be increased and beamline networks will be either 1 or 10 Gb/s on copper or 10/25/100Gb/s on Fibre as experiment demands dictate. WLAN will be available throughout including a new installation inside the tunnel and all cabling will be singlemode fibre.

The zone concept will remain as currently within SLS although the infrastructure itself will be refreshed. On the accelerator the EPICS machine network will be subnetted and built with /24 networks, an increase from the /16 currently in SLS. There will be additional nonEPICS machine networks reflecting what other facilities currently have at PSI.

Each beamline will have its own segregated network that cannot be seen by other beamlines but there will be a common service VLAN network shared between all beamlines. There is an additional option to increase the current data acquisition network from the detectors to the storage from 100Gb/s to 200Gb/s.

The PSI site network is connected to the general Swiss network via highly redundant 100Gb/s network connections as well as the aforementioned dedicated network connections to CSCS. For overview see Figure 4.4 of Ashton et al. [3]

CASIT AND PROJECT MANAGEMENT

PSI is a highly structured organisation with multiple divisions supporting various infrastructure and research which are consequently matrixed for strategic projects including the SLS 2.0 upgrade. There is a strong cultural and professional expertise and pride along with a very high standard and quality of work as would be expected in a Swiss national facility.

Building on the successes of past projects [20] and recognising the critical importance CaSIT areas now play in the success of an upgrade comparable to SLS 2.0, the subproject was created and included at the highest level of the SLS 2.0 project and management board (Fig. 2).

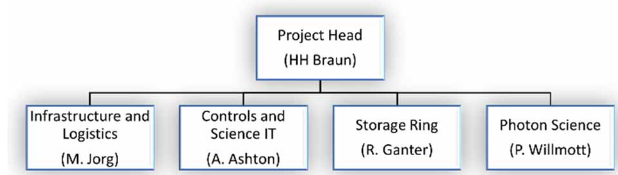

Figure 2: The hierarchy of the SLS 2.0 project management board, [1].

This level of visibility and inclusion offered significant benefits such as:

- The immediate consideration and impact on CaSIT activities, availability and schedule when any scope changes were being considered.
- A dedicated budget line that was ringfenced (circa 4% of the overall upgrade budget).
- Direct communication line to the workgroups in CaSIT both from the SLS 2.0 management board or to the management board for any matters needing escalation.
- Increased and simplified processes for standardisation.

While CaSIT contributors benefited and continue to profit from this inclusion, the cultural change and matrixed nature of the subproject did highlight a number of challenges including:

- Gathering and agreeing requirements and prioritisation.
- Identifying budgets that were historically embedded with other activities and ensuring none were overlooked or double accounted.
- Establishing, documenting and communicating clear responsibilities and decisions in a resource stretched environment where other external pressures persist on the involved units.

- The critical nature of involving and delegating decisions and priorities to a combination of technical and scientific expert stakeholders.

CONCLUSION

A significant amount of effort has already been invested in the SLS 2.0 project in preparation of the SLS dark time. By evolving from past projects and forming a dedicated subproject for controls and science IT, the stakeholders have a higher degree of confidence that there will be a reduced risk of unforeseen problems arising from this critical layer of infrastructure. While recognising no structure is perfect, those involved in the CaSIT subproject recognise the structure has given them a better platform and visibility in the overall initiative. As with all large-scale infrastructure projects, there will inevitably be unforeseen surprises but with continued vigilance, the structure should serve to reduce unnecessary misunderstandings and missed opportunities, responsibilities or tasks.

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