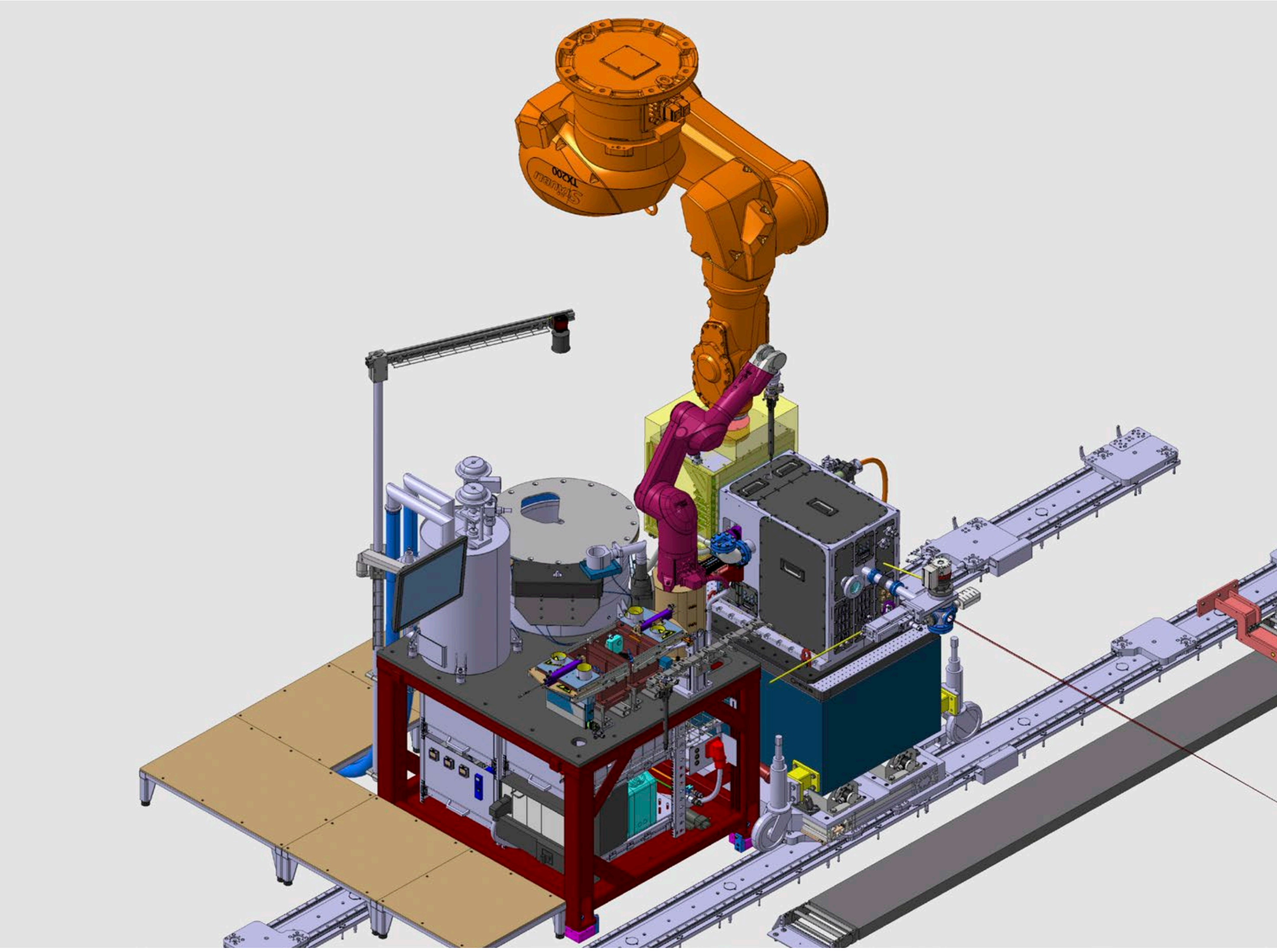
PAUL SCHERRER INSTITUT



Co-Creating the Digital Future

Providing a platform to co-develop, exchange and share advanced digital technologies

Digitalisation means collaboration

Today nearly all of our everyday activities are impacted by digitalisation: from private and social interactions through to business and science. The intelligent networking of people, machines, systems, logistics and production processes has resulted in entirely new forms of organisations and value-added processes. These cyber-physical innovations represent the 4th Industrial Revolution.

Collaboration as a decisive success factor

While it is true that many expectations and forecasts regarding our digital future are still speculative, two things are already clear: firstly, the ways and means by which we, as an organisation or company, master digital challenges will determine our future success in global competition. Secondly, no organisation and no company will be able to master the complexities of digital transformation exclusively using its own resources; there is just too great a demand for a wide range of specialized knowledge and skills that must be drawn from many different disciplines. The ability to work together has thus become a decisive success factor. Only players who ally themselves to the right partners and most effectively bring together their combined expertise will succeed in setting themselves apart from the competition.

Digitalisation partners from science and business

PSI is one of the world's leading research institutes. In particular, it has unique expertise in the development, construction and operation of complex large research facilities. Apart from our engineering and technological expertise, the challenges of digitalisation are assuming ever-greater importance for the development of the next generation of our accelerator facilities. PSI offers specialized partners from science and industry the opportunity to take part in the collaborative development of new digitalisation technologies and for the implementation of pioneer applications.
These co-development partners will also gain access to its highly complex large research facilities and thus a development and testing environment that already anticipates many of the digitalisation challenges which industrial companies will have to face in the years ahead.

Innovation for the next synchrotron generation

Through the creation of a co-development platform we intend to take our long-standing, successful research and development cooperation with leading university institutes, ambitious industrial companies and highly specialized suppliers to a new level. Our goal: The upgrade of our synchrotron Swiss Light Source to the next generation of technology in the form of the SLS 2.0. The extensive digitalisation component of this project, Internet of Things, artificial intelligence, machine learning, wireless networking, high-volume data processing, as well as virtual and augmented reality are all key elements for the necessary performance improvements.
This white paper pinpoints specific areas in which PSI would like to enter into partnerships. These include data scientists, suppliers of information and communication technology as well as companies in sectors such as sensor technology, analogue and digital electronics, automation and process control.

Have we aroused your interest? If so, please do not hesitate to contact us. We look forward to joining forces with you to spearhead the digitalisation process in Switzerland.

Best regards

Prof. Dr. Joël Mesot,
Director Paul Scherrer Institute

Content

4 A platform for digital innovation

- 4 The Swiss Light Source SLS
- 4 Co-development is in PSI's DNA
- 4 The SLS 2.0: A complex high-throughput photon facility
- 4 Extremely high sensor density and data volumes

6 High-bandwidth and low-power wireless technologies

- 6 Challenges of the SLS 2.0
- 6 What wireless networking partners can expect from PSI
- 6 Use cases for wireless networking partnerships

8 Internet of Things

- 9 Challenges facing the SLS 2.0
- 9 What IoT partners can expect from PSI
- 9 Use cases for IoT partnerships

10 Artificial Intelligence and Machine Learning

- 11 Challenges of SLS 2.0
- 12 What AI and ML partners can expect from PSI
- 12 Use cases for AI and ML partnerships

14 Virtual Reality and Augmented Reality

- 14 Challenges facing SLS 2.0
- 15 What VR and AR partners can expect from PSI
- 15 Use cases for VR and AR partnerships

16 High-volume data throughput and management

- 16 Challenges of SLS 2.0
- 16 What data processing partners can expect from PSI
- 16 Use cases for partners

18 PSI at a glance

- 18 Key figures (2016)

A platform for digital innovation

The largest research institute for natural and engineering sciences in Switzerland, PSI operates a globally unique combination of large accelerator-based research facilities. Every year, these facilities are used by over 2500 academic and industrial users from Switzerland and elsewhere around the world. PSI's core competences include the development, construction and operation of these complex installations, with around 1000 specialist scientists, engineers and technicians being engaged in these areas.

The Swiss Light Source SLS

The Swiss Light Source SLS at the Paul Scherrer Institute is one of the institute's four so-called large research facilities. It is a super-microscope that can reveal features a million times smaller than a grain of sand. The SLS makes super-bright, pin-point sharp beams of X-rays and ultraviolet light. These are used to learn how the external appearance and behaviour of objects is linked to what is inside. They can reveal how atoms and molecules inside an object are connected together and how they interact. Experiments at the SLS are essential for advancing science and solving problems in industry, by addressing contemporary issues in medicine, energy, the environment, and engineering from food processing to computer chip fabrication.

Co-development is in PSI's DNA

To meet the wide-ranging demands placed on ever more complex installations, PSI has, from the very beginning, supplemented its own areas of technological expertise by engaging in close development partnerships with specialist university research groups and technology suppliers. The planned upgrade of the synchroton Swiss Light Source SLS to the next generation in the form of the SLS 2.0 will bring greatly increased technological demands, particularly in the field of digital data communication and processing, but also with regard to connecting existing industrial technology with newer digital technologies. To meet the challenge of this huge advance in performance goals and ensure the long-term success of its partnerships, PSI is establishing a co-development platform targeted at existing and new partners involved in:

- **basic research.** Partners who wish to develop new concepts and technologies in the fields of data communication and the collection and processing of very large volumes of data;
- **applied research.** Partners who wish to develop and test applications of ground-breaking digitalisation technologies;
- **engineering.** Partners who wish to develop and test future information and communication technologies for industry as well as innovative ways of connecting industrial technology to cyber-physical systems using digital technologies;
- **digitalisation.** Partners who themselves wish to establish pioneering digitalisation applications or cyber-physical systems with technical demands similar to those for SLS 2.0.

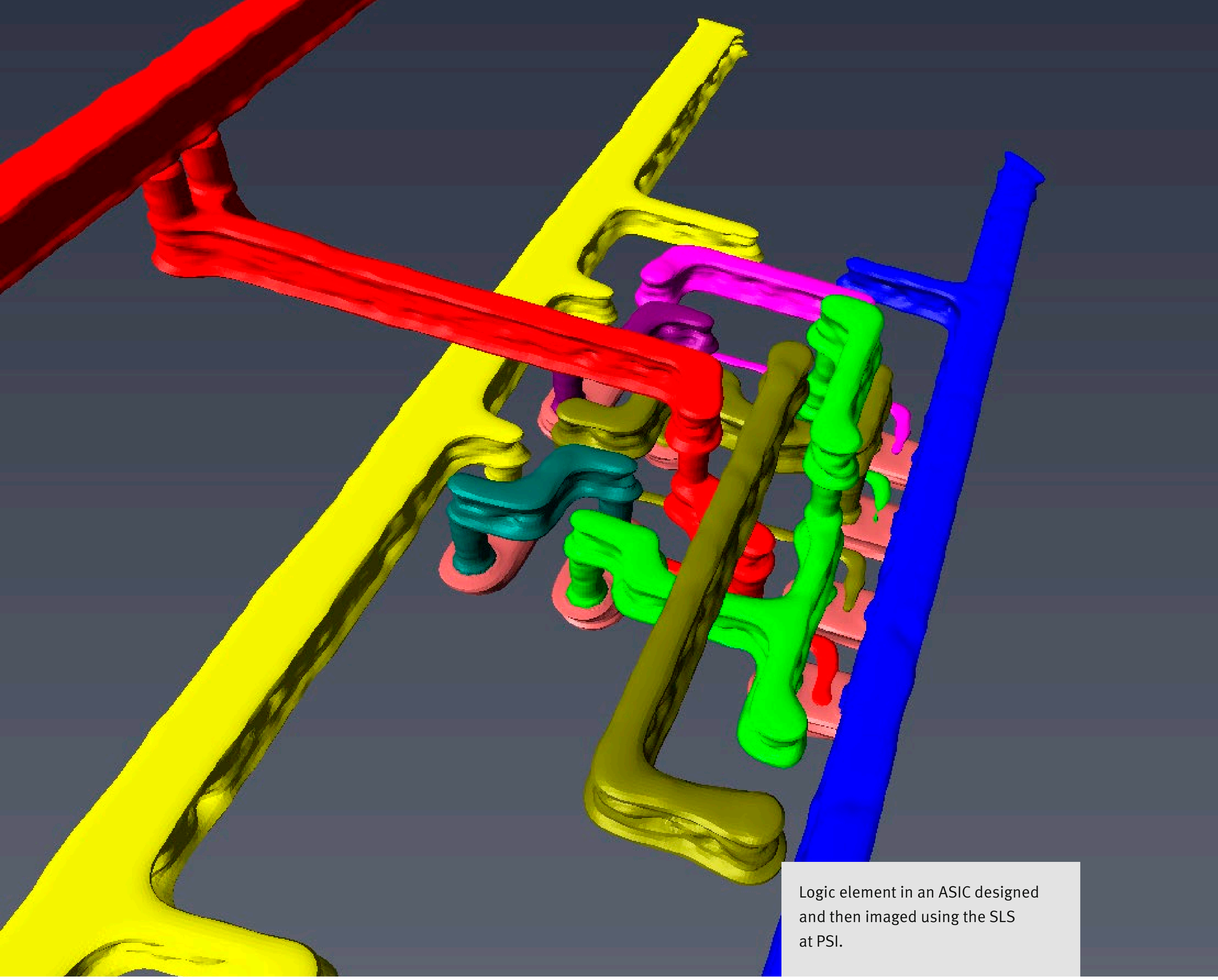
The SLS 2.0: In essence a highly complex photon production facility

In essence, the SLS 2.0 can be compared to a large-scale industrial production facility: Its product will be synchrotron light of the highest degree of brilliance, which will be emitted by means of accelerated electrons. What distinguishes SLS 2.0 from a "normal" production plant is its extremely high degree of complexity and flexibility. This combination of complexity and flexibility is a challenge which is also faced by conventional industry.

Extremely high sensor density and data volumes

Two features of the SLS 2.0 will set it apart from other particle accelerators, from existing large research facilities, and from industrial systems:

1) The exceptionally high number of sensors and actuators (approximately 100 000) required for the precision monitoring and control of the installation;
2) The vast volumes of data (in the region of hundreds of terabytes a day) created by the experiments carried out at the SLS 2.0 and the overall system monitoring, requiring real time automated analysis.



Logic element in an ASIC designed and then imaged using the SLS at PSI.

This makes the SLS 2.0 both a blueprint and a test arena for the industrial manufacturing plants of the future, which will themselves eventually achieve a comparable density of sensors and similar volumes of data in the years to come. The use cases which PSI would like to address in co-development partnerships relate to some of the main challenges that will need to be overcome on the path to Industry 4.0. They focus on the following areas:

- **High-bandwidth and low-power wireless technologies:** Required for the large network of system components and sensors. The large number of sensors needed means that a wired network alone is not practicable, for reasons of space and cost and flexibility.
- **IoT (Internet of Things):** The IoT concept will form one of the underlying principles of a control and monitoring architecture which can be adapted flexibly to changing needs. It will also enable the construction of highly complex systems. Autonomous sub-systems with local intelligence will need to act in conjunction and enable real-time data analysis and control.
- **Artificial Intelligence and Machine Learning:** The extensively automated operation of the complex installation and the development of cost-efficient predictive maintenance concepts are in practice only feasible with the aid of Artificial Intelligence (AI) and Machine Learning. The SLS 2.0 will therefore require a large number of different and interacting AI applications.
- **Virtual Reality and Augmented Reality:** These technologies should both significantly simplify the visualization and analysis of the extremely large and complex data records and simplify the monitoring and maintenance of the complex systems.
- **High-volume data throughput and management:** The extremely high volumes of data which need to be processed for the automation of the installation's operation and which are also created during the scientific measurements, will place exceptional demands on data management and data processing systems.

High-bandwidth and low-power wireless technologies

One of the underlying principles of Industry 4.0 is to achieve the most extensive possible networking between all the components in systems and processes. In many cases, the use of wireless technologies will be indispensable in order to adapt the communication between these components as flexibly as possible to new or changing requirements. Not only is the installation effort involved in re-siting wired communication technologies or incorporating new elements into existing ones much greater: for many wired components the initial installation is also expensive and time-consuming. There is also the additional problem that many systems simply do not have enough room for large amounts of new cabling.

If wireless installations are to be able to take on the majority of networked communication, the scalability, reliability, security and performance of current wireless technologies need to be further developed. Here, major research establishments can assume a pioneering role, as they are among the first users to work with wireless networks of this level of sophistication.

Challenges of the SLS 2.0

The new SLS 2.0 light source is going to be equipped with around 100 times as many sensors as the current system. The additional data collected will help to further increase the quality of the measuring beam, allowing new scientific questions to be addressed. At the same time, the data will also contribute to the further automation of the operation of the plant and help optimise this process.
For reasons of space, cost and flexibility, the vastly increased number of components in the SLS 2.0 can no longer be connected exclusively using cable-based technologies. Moreover, the majority of the sensors will have to communicate wirelessly with the central and non-central control elements; this throws up new challenges, as the large number of communicating elements could likely exceed the performance capacity of existing wireless technologies. This fact is all the more relevant as a high degree of reliability and real-time capability is needed for the automation of the plant control system.

What wireless networking partners can expect from PSI

The wireless infrastructure of the SLS 2.0 will be among the most sophisticated ever produced, featuring a very large number of sensors and actuators communicating wirelessly. The interaction of various wireless technologies needed for different requirements in various areas of the system is a challenge. It will make the SLS 2.0 an ideal development and test environment for highly scalable, efficient and flexible wireless installations of the type that will be required by industry in the near future. Through the SLS 2.0 Development Platform, wireless networking partners will also gain direct access to specialist companies and research groups from other areas of digitalisation, including IoT, Artificial Intelligence, Machine Learning, Virtual Reality, Augmented Reality and high-volume data technologies.

Possible use cases for wireless networking partnerships

Collision-free wireless communication
In wireless communication, signals transmitted at the same frequency can eliminate each other. This effect increases exponentially with the size of the wireless network and can cause data rates to fall drastically to just a few data packets per second. The SLS 2.0 sensor network, based largely on wireless communication, requires technologies and wireless architectures that preclude this sort of collision.

Wireless communication in RF system environments
Mobile wireless sensor equipment is very useful for diagnostic analysis of the SLS 2.0 radio frequency (RF) systems which are used to accelerate the electrons in the injectors and in the SLS storage ring. The status and behavior of these critical systems can be monitored much more specifically and accurately using temporary installations, so portable systems are being developed which should work faultlessly under the particular conditions of the RF systems environment. They must be immune to disturbance from the RF systems, while at the same time the radiation from the wireless network must not interfere with the sensitive RF sensors.

Optimal wireless technologies for different requirements

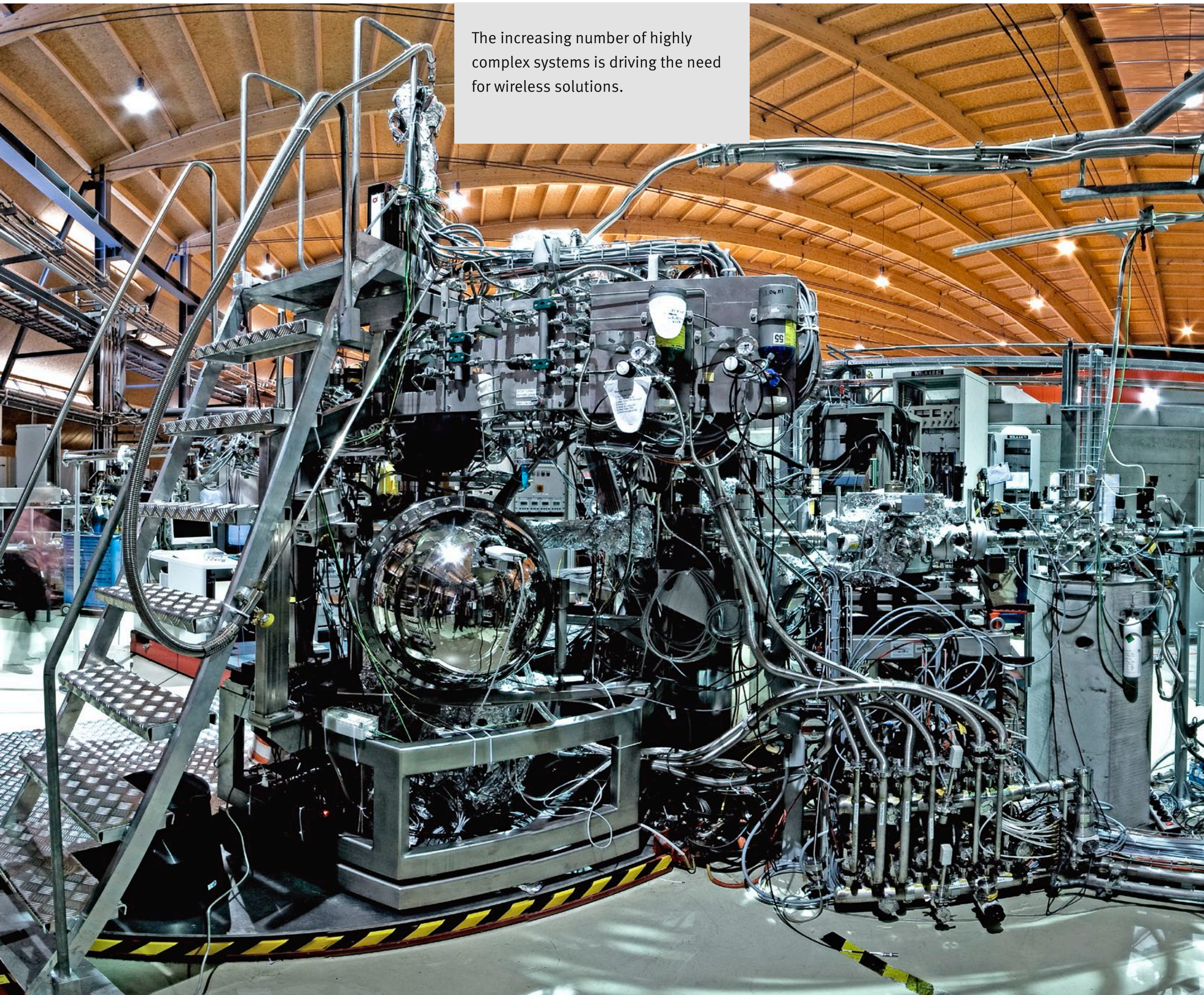
The various standard wireless communication systems in existence today have all been optimised for very specific applications. They differ particularly in terms of their frequency band, susceptibility to interference from other wireless technologies or shielding materials, data rates, reliability, energy consumption, cost, sensitivity to radiation and real-time capabilities. Different types of wireless technology will therefore be used in the SLS 2.0, depending on the nature and location of the application.

Interplay of different wireless technologies

The architecture of the network must be designed to ensure that the various wireless technologies used in the SLS 2.0 do not interfere with each other. In particular, this must involve meeting the higher-level demands placed on a unique and rapid control and monitoring hierarchy with excellent reliability. In addition, it is necessary to select a network structure that allows individual components, technologies or network areas to be changed at any time, with flexibility and in a cost efficient manner.

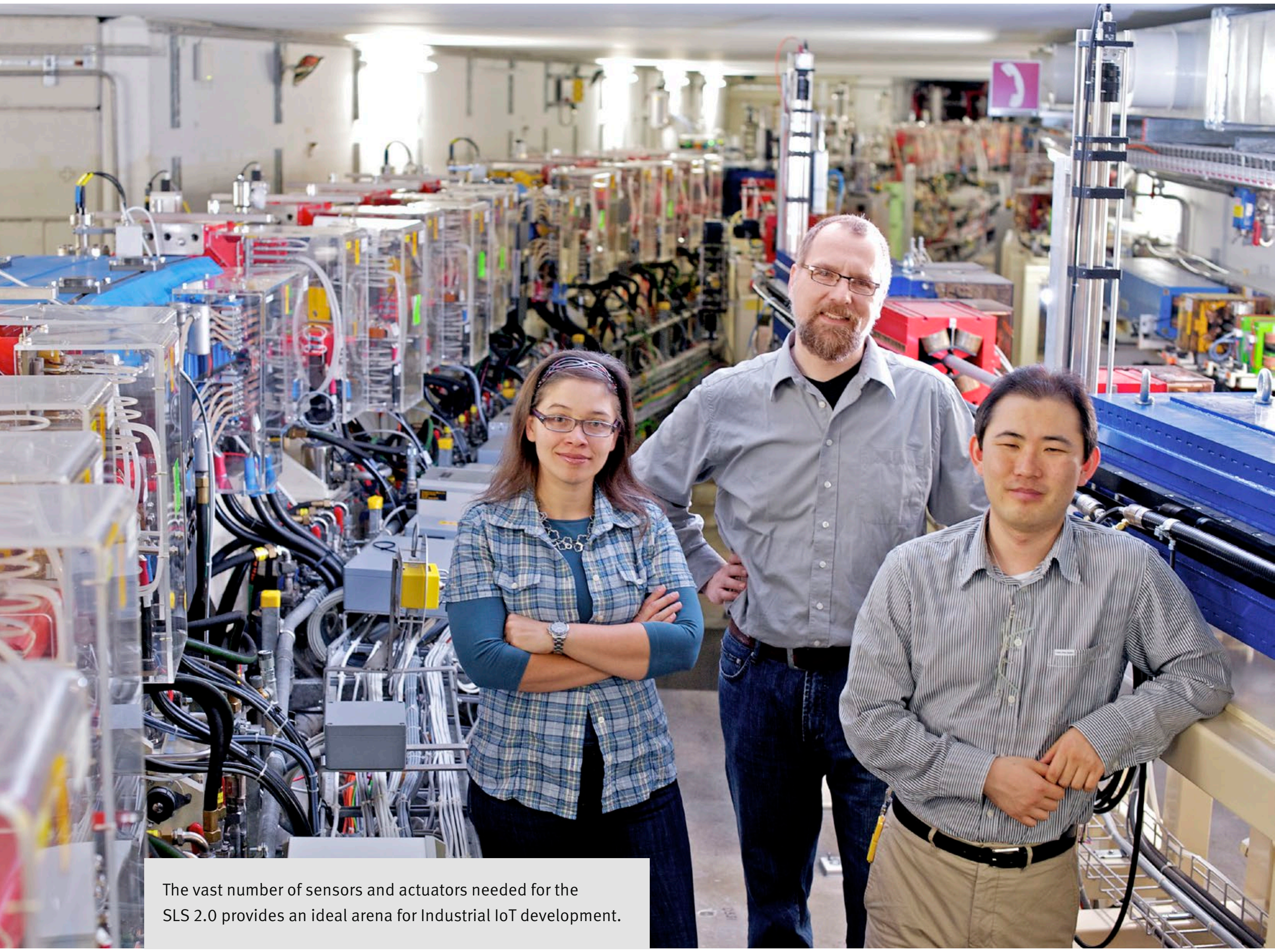
Security in heterogeneous wireless networks

The security of the SLS 2.0 wireless networks must be guaranteed at all times. An external attack could have devastating consequences for the extremely expensive system, so an architecture must be found which combines different secured network zones and authentication and encryption technologies to achieve an optimum balance between security, performance and cost. The sophisticated SLS 2.0 wireless installation is therefore an ideal test environment for security architectures belonging to future industrial IoT solutions.



The increasing number of highly complex systems is driving the need for wireless solutions.

Internet of Things



The vast number of sensors and actuators needed for the SLS 2.0 provides an ideal arena for Industrial IoT development.

As part of the digital transformation to Industry 4.0, the Internet of Things will play a fundamental role. The fast-growing number of networked sensors and actuators needed for automated, intelligent control of large plant and systems requires a new, decentralised communications architecture. To master increasingly complex systems, intelligence needs to be organised in wholly or partially autonomous units, much like the Internet. In an IoT architecture, the interplay between the disseminated intelligent components together with superordinated, system-wide coordination guarantees optimum operation for the entire system configuration. On top of this, an IoT architecture is also ideal in fulfilling the growing need for maximum flexibility. Additional components can be integrated into an IoT network with a minimum of effort.

Challenges facing the SLS 2.0

Even today, with the help of networked sensors and actuators, PSI's particle accelerators are automatically controlled to a significant degree. With the projected next generation of the synchrotron Swiss Light Source (SLS 2.0), the number of sensors will be multiplied by up to two orders of magnitude. These additional sensors will supply significantly more precise system and environmental data. With their help, the quality of the light beam, and with it the validity of the scientific experiments, will be significantly improved and the required effort of operation reduced.

The massive increase in the number of networked components makes a new network architecture essential. In the SLS 2.0, the current direct wiring solution will not be practicable because of the lack of space and the prohibitive costs. In all situations where maximum signal quality is not essential, wireless data transfer technologies will be used. On top of this, it will be necessary to decentralise certain parts of the system intelligence either directly to sensors or to various diversified local computing nodes. Only in this way will it be possible to deliver real-time processing of the enormous amounts of data. The third need relates to flexibility. In future, sensors and actuators will need to be easily adaptable to the new and changing needs of the user experiments. Finally another unusual challenge comes in the form of the radiation load in the accelerator tunnel, which can result in the destruction of conventional electronic components.

What IoT partners can expect from PSI

As a synchrotron Light Source of the fourth generation, the SLS 2.0 will feature one of the most sophisticated IoT installations to date. Every day, up to 100 000 sensors and actuators will generate terabyte-sized data volumes that will need to be processed in real time. The SLS 2.0, therefore provides an ideal development and testing environment for future oriented IoT infrastructure development. University research groups and ICT providers will benefit as partners not only from PSI's many years of experience in the successful management of collaborative projects. The SLS 2.0 co-Development Platform also creates direct contact with specialist companies and research groups from other digitalisation sectors such as wireless networking, artificial intelligence, machine learning, high-volume data technologies as well as virtual and augmented reality.

Possible use cases for IoT partnerships

Optimisation of network traffic

In the SLS 2.0 IoT network, thousands of elements and nodes will communicate with each other, exchanging very large data volumes on a terabyte scale. The search is on for technologies which, on the one hand, prevent bottlenecks occurring during the transfer of data but which on the other hand secure a fast and unequivocal command hierarchy that is needed for the automated control of the entire system in real time.

Scalability of secure IoT technologies

The unusually large scale of the IoT installation makes the SLS 2.0 an ideal test environment for the scalability of IoT technologies. Thousands of sensors and components must function together. At the same time, the system must be able to handle enormously high data volumes reliably and without huge losses in performance. This places unusual demands on individual components and the way they interact. In addition, the security of all radio components and of the entire system must be guaranteed at all times. Unauthorised manipulation from the outside would have potentially disastrous effects for the system.

Optimal IoT architecture

One crucial feature of IoT networks is the decentralisation of intelligence to the individual network elements. First, it makes networks more flexible as additional autonomous or partially autonomous components can be integrated with relatively little effort. At the same time, it minimizes network traffic because certain data processing tasks can be carried out at an earlier stage in intelligent sensors or network nodes. In the ultra-complex and data-intensive SLS 2.0 IoT installations, optimum distribution of the intelligence within the network assumes a decisive role.

Standard components in environments exposed to high levels of radiation

In the accelerator tunnel, where a large proportion of the sensors needed for more precise determination of the environmental parameters, radiation in some areas is noticeably higher. This phenomenon can result in serious malfunctions in electronic components. The search is therefore on for solutions that permit the use of cost-efficient standardised components even in these extreme operating environments.

Artificial Intelligence and Machine Learning

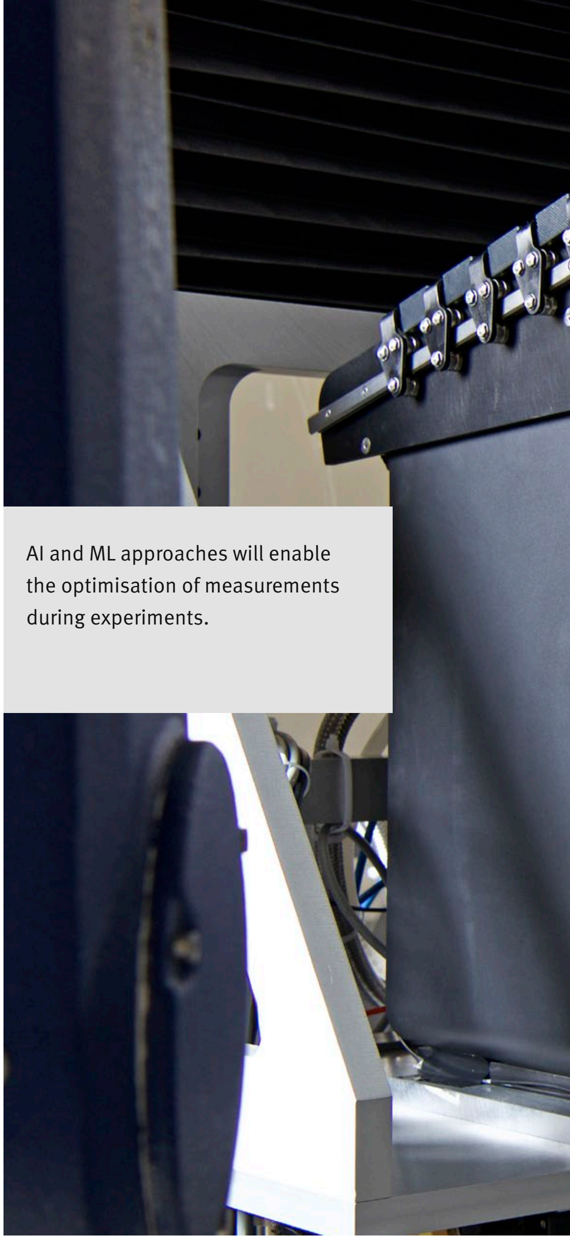
Artificial Intelligence (AI) and Machine Learning (ML) are the keys to the next level of automation. They enable the creation of machines and systems capable of adapting automatically to changing situations, learning from their own experience and making autonomous decisions based on what has been learned. AI and ML technologies are expected to increasingly impact the degree of automation within all economic processes, from supply chains and transport, production and services through to all aspects of possible customer interaction.

The impressive performance of experimental self-driving vehicles demonstrates that this technology has already reached a level of development which suggests that practical industrial applications will also be possible in the foreseeable future. Today's need is for pioneers to collaborate within environments in which the AI applications of the future can be developed and tested under industrial conditions.

Challenges of SLS 2.0

The fourth-generation Swiss Light Source at PSI (SLS 2.0) will provide an extremely complex production environment. The overall number of sensors will increase to around 100 000 – approximately double the number in the current synchrotron, with the total number of process variables increasing to 5 million. Added to this is the fact that like any major production facility, the SLS 2.0 will comprise of a large number of independent sub-systems and components. These will create a highly complex control network with a high number of potential error states, many of them unforeseeable. This results in fundamental limitations on conventional automated control, which is typically based on statically programmed expert systems.

The fourth generation Swiss Light Source (SLS 2.0) will provide a highly complex production environment ideal for the development of an AI/ML based autonomous "digital operator".



AI and ML approaches will enable the optimisation of measurements during experiments.

AI and ML technologies, on the other hand, can learn to adapt to such unforeseen situations. This capability will enable the achievement of extensive automated control of the accelerator operation, as well as the automation of individual application processes, such as in the area of experiments. At the same time, the complex accelerator facility with its extensive IoT installation and extremely large data quantities also provides an ideal environment in which to develop extensive system monitoring which will allow the identification of nascent faults and mitigate them even during ongoing operation.

What AI and ML partners can expect from PSI

The SLS 2.0, with its extremely large volume of measurement data arising from hard-wired sensors and IoT infrastructure, provides an ideal environment for the development and testing of AI- and ML-based control technologies. Particularly interesting for partners from the fields of academic research and industry will be the interplay of various AI, ML and expert systems for planning, optimisation, forecasting, diagnostics, model based learning, and rule based decision-making. In addition to this, AI and ML partners of PSI will also benefit from interfacing with other SLS 2.0 innovations in the areas of wireless networking, data management; data center technologies, IoT, as well as Virtual and Augmented Reality systems. PSI has many years of experience in co-creation partnerships, providing a strong foundation for project success.

Possible use cases for AI and ML partnerships

Automation of partially autonomous sub-systems

The SLS 2.0 will comprise of a variety of sub-systems and components which will ordinarily require the intervention of highly trained specialists during certain phases of its operation. These systems include, among others, the radio frequency (RF) sub-systems for accelerating electrons, the macromolecular crystallography measuring stations and the mechanisms for monitoring the X-ray beams. Replacing human activity with AI and ML technologies in these areas will lower costs, improve quality and increase overall productivity.

Automation of maintenance tasks

Maintaining and servicing a complex production system such as the SLS 2.0 involves many time-consuming routine tasks. These include re-starting the complete facility or various sub-systems after shut down. The work steps involved in this are ideally suited to being automated with the aid of AI and ML.

Optimisation of multi-layer processes

Interrelated multi-layer processes are characteristic of the operation of production systems like the SLS 2.0. They include monitoring of the X-ray beam and conducting macromolecular crystallography experiments to determine the three-dimensional structures of biomolecules. AI technologies can also help coordinate the optimisation of overlapping activities. In the case of crystallography experiments, the aim is to create an "in-silico crystallographer" (ISX) which will be capable of conducting experiments completely autonomously, including sample analysis, experimental configuration and data collection.

Development of a digital operator

AI and ML technologies are already being used today to develop systems which are as autonomous as possible. One of PSI's long-term goals is to create a software-based "digital operator" that can manage the normal operation of the accelerator with complete autonomy. At the SLS 2.0, detailed operating data and extensive environmental parameters will be available, providing the ideal basis for development of automation in the form of an AI/ML driven digital operator.

Development of preventive maintenance

Extremely detailed data, acquired with the aid of IoT installations on machines and the encompassing environment, can be applied in combination with adaptive systems to generate very precise statements about the current status of the overall system. It then becomes possible to make increasingly accurate predictions concerning the long-term behavior of a machine, in the same way that weather forecasts are calculated. This brings the concept of predictive AI maintenance into the realms of possibility, with functional faults being detected even as they arise, and before they can cause damage. This will reduce downtime and significantly improve the ability to plan maintenance work. The SLS 2.0, with its extensive IoT installations and the increasing use of AI technologies, provides an ideal environment for developing and testing such predictive models.

AI and ML-supported measurement optimisation

The quality of biological samples for X-ray structure analyses is very varied. On top of this, the radiation degrades the samples during the measurement process. It is therefore necessary to optimise the parameters of an experiment during the course of a series of measurements in order to obtain the best possible results. With the aid of AI, the optimisation of the measurement parameters for an individual sample can be automated, and the overall quality improved over time using ML approaches. This would not only speed up and improve the measurement process itself, but would also enable investigation of biomolecules that are less easily crystallized.

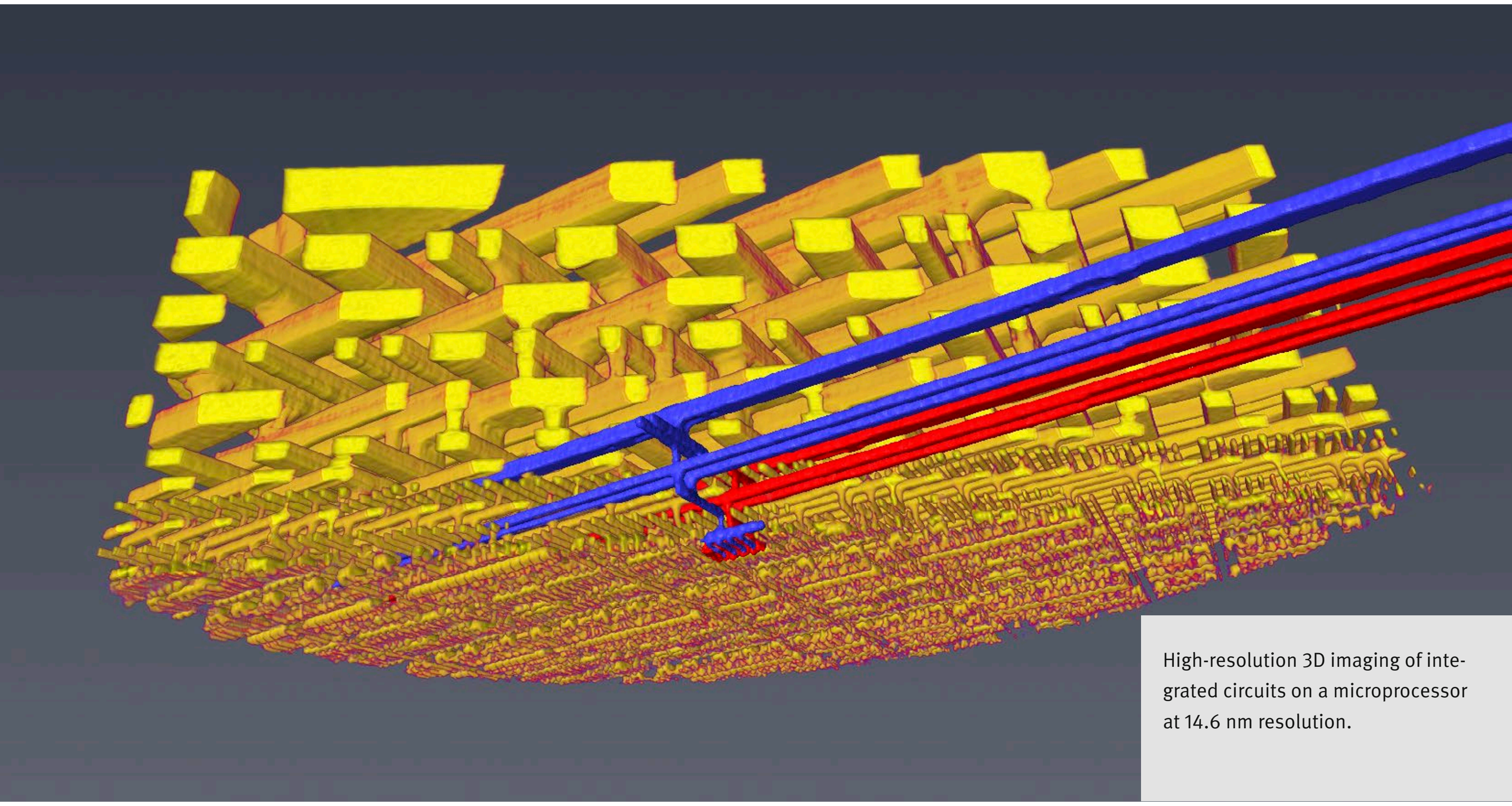
Optimisation of IT operation

Large and irregular volumes of data place great demands on the operation of network and server infrastructures. With the aid of AI and ML, network traffic and allocation of server resources can be automatically optimised, reducing pinch points to a minimum. Improved utilisation also leads to a reduction in hardware costs and energy consumption. In the field of predictive maintenance such an optimised system could also be used to improve procurement planning.

Optimisation of human-AI cooperation

The introduction of AI and ML technologies is generally implemented as a gradual process, which effectively results in the creation of numerous interfaces between the intelligent machine and human experts. Where and how the boundaries are drawn and the way the details of the interaction are designed has a major impact on system productivity. As well as technical parameters there are also psychological factors that can influence the outcome. A human who feels patronised by a machine will suffer from poor motivation and is likely to under-perform. At PSI, user experience specialists and researchers will develop, test and optimise new concepts for AI-human interfaces with the goal of ensuring an optimal productive working environment.

Virtual Reality and Augmented Reality



High-resolution 3D imaging of integrated circuits on a microprocessor at 14.6 nm resolution.

Today, traditional two-dimensional computer screens are only one of the possible technologies suitable for displaying computer data. The use of a virtual reality (VR) headset makes three-dimensional access and content manipulation a viable possibility, while Augmented Reality (AR) overlays the field of vision with additional facts and images. In this way, entirely new possibilities for visualising and interactively navigating data become possible. They make the relationship between data and the real world visible and expand the variety of possible models of data interaction and comprehension. VR and AR have become central tools for digitalisation, while conventional visualisation methods have become increasingly unsuited for displaying huge volumes of information and the ever-more complex connected systems that we are confronted with.

Challenges facing SLS 2.0

The SLS 2.0 will generate vast amounts of data both during system operation and actual experiments. Just how well data can be collected and evaluated depends to a significant degree on the way they are displayed. For instance, for system control, it is essential that not only the state of the entire system is summarized but also the detailed states of all subsystems are observable. If necessary, an operator must intuitively be able to gather data quickly and easily from lower system levels, all the way down to individual sensors and actuators. The same hierarchical approach applies to data obtained during experiments, where visualisation is becoming increasingly crucial to understanding the experimental results. In addition, there is an increasing need for scientists from other countries to carry out SLS experiments remotely from their own institutes. Using VR technologies, researchers from elsewhere can have realistic, interactive access to the SLS 2.0 experimental environment.

What VR and AR partners can expect from PSI

The enormous volumes of data and the fundamentally experimental nature of the system make the SLS 2.0 an ideal environment for the development and testing of VR and AR technologies. At the same time, users can choose from a huge selection of possible applications. They range from the visualisation of a large multi-layered production system and the spatial representation of complex molecular structures through to remote virtual experimentation and support of service technicians. Via the SLS 2.0 co-development platform, VR and AR partners will also enjoy direct contact with specialised companies and research groups from other digitalisation sectors such as IoT, wireless networking, artificial intelligence, machine learning and high-volume data technologies.

Possible use cases for VR and AR partnerships

Visualisation of the entire production system

Through a three-dimensional visualisation of the entire production infrastructure with the help of VR and AR technologies it will be possible to obtain a spatial display of intentional changes and their effects. The latter simplifies planning as well as cooperation between geographically remote teams of engineers. By integrating operating data into this model system, it is also possible for external specialists to offer remote support to PSI technicians in the event of problems.

Remote control of experiments

Researchers all over the world can be given access to the SLS 2.0 experiments. With VR and AR technologies external scientists will be able to control and monitor their SLS 2.0 experiments without being physically present. Interactive VR displays of experimental environments will also give researchers as realistic an impression as possible of the experiments and thus provide optimum opportunities to proactively intervene when necessary.

Visualisation of complex system data

In a complex system, it can be difficult to identify the responsible components in the event of an error. A 3D-visualisation of the system could automatically highlight the error source and also show the relevant parameters of the associated and surrounding components. Given this information, operators will be able to gain an overall impression of the incident and know where to intervene most effectively. A typical example of this might be the detection of a leak in the accelerator vacuum system.

Visualisation and manipulation of 3D protein structures

The results of the X-ray crystallographic measurements of a synchrotron light source are shown in three-dimensional density charts. Their actual molecular structure is then derived with the help of specialized software. In this process, the individual modules of the biomolecules are adapted to the density profile using a trial-and-error approach. Three-dimensional VR visualisation massively simplifies the process by allowing researchers to navigate freely in the data model and to manipulate it at will. At the same time, a system of this kind improves cooperation between geographically remote research groups. It enables them to work more simply and intuitively on three-dimensional molecular models.

AR support for technicians

Support for service technicians involving the use of AR technologies is already a reality in various industries, such as the maintenance of jet engines. Here, the technician is able to project detailed plans or data of the components she is observing with the use of a data headset into her field of vision. This allows her to keep both hands free to work and to locate an element in the system much more reliably. Apart from speeding up service and maintenance work, such an AR support system for the highly complex SLS 2.0 will free up individual subsystem specialists. Thanks to AR support, less qualified technicians will also be able to carry out a wider range of tasks.

Cooperation between remote research groups

Knowledge is global. This is especially true of the SLS 2.0. As a synchrotron light source of the fourth generation, it will attract researchers from all over the world. VR and AR technologies should therefore further help to improve cooperation between PSI and the worldwide community of researchers and accelerator specialists. VR should help engineers to exchange ideas with colleagues working with other, similar systems using 3D models, and will also enable PSI scientists to discuss the structures of materials being examined with research groups from other institutes.

High-volume data throughput and management

Data is the fuel that powers digitalisation. The larger the data volume, the more accurate analysis becomes, and systems can be controlled with ever greater precision. As a consequence there has been a dramatic increase of data needing to be processed and managed in computer centers. Traditional data processing center architectures are increasingly reaching their limits. To exploit the full potential of IoT, Artificial Intelligence and Machine Learning we need new, cost-efficient concepts for the storage, analysis and archiving of very large amounts of data. Large research facilities, which are among the first to encounter these limitations, provide opportunities for pioneer solutions that can later be adopted by industry, following the pattern for the World Wide Web which originated at CERN.

Challenges of SLS 2.0

The SLS 2.0 presents PSI with huge data processing challenges. The number of sensors in the overall system will increase by two orders of magnitude while at the same time there will be a three to four orders of magnitude explosion in the quantity of data generated by the detectors at the experiment stations. The increases in capacity are of course at the heart of the science case for SLS 2.0 as they correspond to individual measurements with up to 100-fold increases in spatial resolution and frame rate increases up to four orders of magnitude. There will therefore be extreme demands on data acquisition and storage systems, implying a tiered architecture in which data can be reduced intelligently and then processed cost-efficiently on different high-performance hardware depending on the individual use case. To manage the extremely large and fluctuating amounts of data. Cloud infrastructures will also have to be integrated so that internal and external resources can be pooled, keeping in mind the need for confidentiality of the data and associated protocols when proprietary and national security related research is performed.

What data processing partners can expect from PSI

The SLS 2.0 will be one of the most demanding production plants in the world in terms of data processing and management. At the same time, it is necessary to find cost-efficient solutions. This makes it an ideal development and test environment for new technologies and concepts for architectures that can later be used in industry. All aspects of high-performance data processing, from real-time data reduction and layered infrastructures to Cloud models, can be addressed. Partners will also profit from PSI's close cooperation with other major European research establishments, including its involvement in the European Open Science Cloud project. As data processing and data management partners of PSI, scientists and ICT providers will have access to direct contacts within other SLS 2.0 innovation projects in the fields of Wireless Networking, Artificial Intelligence, Machine Learning, IoT and VR and AR.

Possible use cases for partners

Technologies for data recording and reduction

Future generations of scientific detectors in the SLS 2.0 will generate up to ten thousand times more data than existing detectors. This is mainly due to the planned increase in the measurement frequency up to 100 kHz, which will allow the maximum data rate of each individual detector module to increase into the region of several terabytes per second. This alone will present new technological challenges with regard to reading data from the detectors and storing it. Intelligent filter systems will also be required to make the large data volumes manageable. As far as possible, these should be able to reduce the raw data in steps and in real time in such a way that no relevant information is lost.

Distributed architecture for storage, analysis and archiving

The various data that the SLS 2.0 will produce will have very different requirements in terms of the priority of analysis, speed of access and duration of storage. A multi-layer storage architecture is needed to manage the vastly increased amounts of data in a cost-efficient way. It should contain very fast storage systems for recording data and real-time analysis, with large and less costly systems to manage less time-critical analyses. For long-term archiving of data, cost-efficient systems with a capacity of several hundred petabytes to several exabytes will be required. This will entail connecting the various

SLS 2.0 presents PSI with expected increases of 3 to 4 orders of magnitude in terms of data collection and processing capability requirements.

data storage pools to enable seamless data flows and interactions.

Cloud models for High Performance Computing

The demands on data processing for major scientific research projects are growing more quickly than the project budgets. One possibility for providing the necessary computer capacity with maximum cost efficiency exists in the form of Cloud models. This means establishing and expanding local capacities at PSI as well as efficiently incorporating resources from other Swiss research institutes and commercial providers. To guarantee computer capacity for scientific High-Performance Computing (HPC) in the long term, PSI is also actively involved in the European Open Science Cloud project. This Cloud will pool together the computer capacities of the most important major European research establishments and HPC centers, so that they can be used more efficiently by all concerned.

Open platform for hardware-independent HPC applications

Currently, applications are specially developed or adapted for HPC systems such as those of the Swiss National Supercomputing Center (CSCS) in a time-intensive process. New technologies are set to change this. The aim is to achieve the greatest possible independence of the application from the hardware on which it operates. A platform which is open in this way will enable HPC resources to be used flexibly – locally, in an HPC center, or in the Cloud, depending on the requirement profile (e.g. performance versus cost). At the same time, a platform of this kind will make HPC resources significantly more accessible and usable for industry users as well.

Secure network architecture for intranet, internet and extranet

IT security is particularly challenging where large-scale technical installations are involved. Often, there is a conflict between the demand for optimum performance and security requirements. For the SLS 2.0 there is the additional challenge of the unusually large IoT network required for the sensor system for the whole installation. Thousands of sensors and actuators communicating wirelessly have to be secured against intentional and inadvertent manipulation, as malfunctions in a complex installation like the SLS 2.0 have the potential to cause major damage. The security architecture will be designed to ensure an optimum balance of protection, performance, openness and cost.

PSI at a glance

Key figures (2016)

The Paul Scherrer Institute PSI is part of the ETH Domain, with the other members being the two Swiss Federal Institutes of Technology, ETH Zurich and EPFL Lausanne, as well as Eawag (Swiss Federal Institute of Aquatic Science and Technology), Empa (Swiss Federal Laboratories for Materials Science and Technology) and WSL (Swiss Federal Institute for Forest, Snow and Landscape Research). PSI employs 2100 people, including some 1100 researchers. It has an annual budget of approximately CHF 380 million, and is primarily financed by the Swiss Confederation. Every year, more than 2500 scientists from Switzerland and around the world come to PSI to use our unique facilities to carry out experiments that are not possible anywhere else.

Large-scale research facilities and accelerators

The Swiss Light Source SLS produces high-brilliance synchroton light (infra-red to hard X-rays) using an electron accelerator. Researchers use this facility to screen a very diverse range of materials and biomolecules, enabling them to determine the composition and structure of the tiniest nano-sized structures.

The X-Ray Free-Electron Laser SwissFEL is an electron accelerator used to produce high-brilliance X-ray light pulses with laser properties. Researchers can use this facility to make extremely fast processes visible such as the creation of new molecules in chemical reactions, as well as enabling them to determine the detailed structure of proteins and explain the precise composition of materials.

The Swiss Spallation Neutron Source SINQ: Neutrons are created by firing a continuous stream of protons traveling at 80 % of the speed of light into a sequence of targets made of lead or carbon. The Protons are sent to these targets by PSI's high intensity proton accelerator. Using neutrons researchers investigate new materials for superconductors or computer memories, or see inside an engine while it is running.

The Swiss Muon Source SμS: Its muons (heavy electrons) are generated in a similar manner to the neutrons at PSI. With muons researchers can detect magnetic fields inside materials. PSI has the slowest muons in the world which are very sought after by researchers from all over the globe.

The Proton accelerator facility: Neutrons come from the SINQ and muons from the SμS when a beam of high-energy protons hits a block of special material. This proton beam is produced in the PSI proton accelerator facility, where protons are accelerated to almost 80 % of the speed of light. The 2200 microampere proton beam makes it the most powerful system of its kind anywhere in the world.

The COMET cyclotron: This is a special accelerator for producing protons for PSI's proton therapy facility, used in the fight against certain types of cancer.

The main technical competences at PSI

- Development and construction of highly complex accelerator facilities
- Operation and automation of highly complex accelerator and research facilities
- Development and manufacture of high-performance detectors for use in accelerators worldwide
- Provision and operation of infrastructures for analysing very large volumes of data

- Management of co-creation partnerships with specialists from science and industry

The three main areas of research

In the field of **Matter and Materials,** researchers look at the internal structures of various substances. Their results help us to a better understanding of processes in nature and provide the basic principles for creating new materials for technical applications. The aim of the **Energy and Environment** area is the development of new technologies for a sustainable and safe supply of energy and a clean environment. Researchers in the **Human Health** section are investigating the causes of diseases and searching for possible treatment methods. At the level of fundamental research, they examine and explain biological processes.

Contacts

Head of Research Division Photonics
Prof. Dr. Gabriel Aeppli
Tel. +41 56 310 42 32
gabriel.aeppli@psi.ch

Head of Technology Transfer
John Millard
Tel. +41 56 310 41 83
john.millard@psi.ch

Imprint

Concept / Text / Editing
Prof. Dr. Gabriel Aeppli
Dr. Markus Janousch
John Millard
Daniel Meierhans
Dr. Giorgio Travaglini
Prof. Dr. Albin Wrulich

Photography
Page 1/10: H. R. Bramaz
Page 2: Scanderbeg Sauer Photography
Page 5/12/17/18: Markus Fischer
Page 7: Andreas Haus
Page 8: Frank Reiser

Layout
Monika Blétry

Printing
Paul Scherrer Institut

Available from
Paul Scherrer Institut
Events and Marketing
5232 Villigen PSI, Switzerland
Tel. +41 56 310 21 11

Villigen PSI, January 2018

Paul Scherrer Institut :: 5232 Villigen PSI :: Switzerland :: Tel. +41 56 310 21 11 :: www.psi.ch