MedCrave
Step into the World of Research
International Robotics & Automation Journal

Review Article
Open Access
CrossMark

AI functionality for research experiments at ring photon source

Abstract

A ring photon source is a powerful research tool for scientists, and built-in or tightly integrated artificial intelligence helps extract the maximum from this tool and significantly accelerate research by optimizing the operation of the facility itself. A ring photon source is a highly complex engineering system. To ensure the electron beam moves stably and produces the brightest and most predictable synchrotron radiation, a multitude of parameters must be monitored in real time: beam current, the position of magnetic elements, the tunnel temperature (sometimes accurate to fractions of a degree), pressure, and vibrations. Artificial intelligence takes on the task of continuously analyzing this data. It automatically adjusts the equipment settings to the researchers' experiments. As a result, the facility operates more reliably, maintains the required parameters longer, and scientists obtain higher-quality experimental data. Once the experiment is completed, the most extensive part begins—processing enormous data sets: spectra, tomograms, element distribution maps, and automated analysis. Neural networks help identify useful signals, filter noise, and find patterns in the data faster and, sometimes, more accurately than a researcher. Based on accumulated data, intelligent models can predict how a material will behave under certain conditions and what structures may form. This allows scientists to narrow their hypotheses before the next experiment, avoiding wasting time on dead-end options. A digital twin of a setup or process can explore various scenarios and fine-tune the experimental methodology without wasting precious time slots on the actual setup. The goal is not simply to automate routine tasks, but to ensure that artificial intelligence helps make decisions quickly, optimizing the entire cycle: from beam setup to results interpretation. As a result, scientists obtain more accurate and reproducible data, reduce the time spent setting up experiments and analyzing them, and therefore can more quickly test hypotheses, discover new properties of materials, develop drugs, or improve technologies.

Keywords: ring photon source, embedded intelligent models, research experiments

Volume 12 Issue 1 - 2026

Evgeny Bryndin
Scientific Director, Research Center for Natural Information Technologies, Russia

Correspondence: Evgeny Bryndin, Scientific Director, Research Center for Natural Information Technologies, Russia

Received: August 22, 2026 | **Published:** September 25, 2026

Introduction

A ring photon source is a gigantic facility where a beam of electrons is accelerated in a ring storage ring to nearly the speed of light. As the electrons move around the ring, magnetic fields cause them to sharply change trajectory. At these moments, the particles emit energy, creating synchrotron radiation—essentially a very bright and narrow beam of X-rays. This radiation illuminates the samples being studied, allowing scientists to study the structure of substances at the atomic level: to observe the structure of materials, proteins, and catalysts, to observe fast chemical reactions, or the dynamics of processes under extreme conditions. A striking example is Russia's Siberian Ring Photon Source (SKIF) in the science city of Koltsovo. This megascience-class facility (generation 4+) has reduced emittance (a parameter directly affecting beam brightness and coherence) to a minimum.[1] Channels extend from the storage ring (its perimeter is 476 meters) to experimental stations, each tailored to its own specific needs: from structural diagnostics to the study of fast processes.

The researcher's journey from idea to experiments at the SKIF station was presented at the XIII International Technological Development Forum TECHNOPROM-2026.

Along with the numerous applications of SR in scientific research, there are a number of studies of significant practical significance, in particular the use of SR in microlithography. The American company IBM conducted a series of studies demonstrating the significant advantages of using SR in microlithography for producing integrated circuit components. This lithography method is used in the production of components for modern semiconductor devices (integrated circuits, microprocessors, etc.) and involves transferring an image from a specially prepared mask to a substrate. Until recently, electron beams or lasers were used to reproduce masks in lithography; both methods did not achieve a resolution better than 2 µm. The use of X-rays can increase resolution by hundreds of times, but with the current power of X-ray sources, exposure times to produce a single image can reach several hours.

Synchrotron radiation is much more intense than existing X-ray sources and produces a virtually collimated beam. This allows for imaging resolution to be increased to hundredths of a micrometer with exposure times of several seconds. Moreover, as the research showed, this can be done with a single mask.

Intelligent systems are planned to be integrated into the ring photon source. These intelligent systems can be used to control the complex and support experiments.[2–7]

Accelerator complex management and control

Here, artificial intelligence solves problems that are difficult to describe with simple formulas due to the many interconnected parameters:

Maintaining beam stability.** Strict temperature conditions are critical: in the tunnel, fluctuations should not exceed 1–2°C, and for the equipment cooling systems, even stricter conditions, around 1°C. Artificial intelligence monitors sensor readings in real time and predicts deviations to proactively adjust system operation. **Control of interconnected subsystems.** An accelerator consists of hundreds of components (magnets, vacuum, RF systems, etc.), where changes in one parameter affect others. Artificial intelligence takes these connections into account and helps maintain the system in optimal operation.

Adaptation to external conditions. External temperature, vibrations, and electromagnetic interference all affect the system's operation. Machine learning models help compensate for external influences to maintain stable beam parameters.

Experiment support and data processing

The role of intelligent systems is especially important at the experimental and analysis stages:

Automated Spectrum Processing. Neural networks can quickly identify peaks, background, and noise in spectral data (for example, in X-ray photoelectron spectroscopy), speeding up analysis by tens of times compared to manual processing. **Stream processing and dynamics.** Artificial intelligence can process large spectral data streams and track changes in sample composition or structure over time—useful for in situ and operando experiments.

Selection of optimal experimental parameters. Based on previous runs and sample characteristics, artificial intelligence can suggest optimal station settings (energies, angles, exposures) to obtain the desired spectra or images.

Extracting useful meaning from complex data. Artificial intelligence helps move from spectral modalities to interpretable features and conclusions, including using semantic and metamodels.

Interaction with researchers

Process monitoring interface. Built-in intelligent models provide researchers with clear summaries of the setup status and experiment progress, visualize key metrics, and alert them to critical deviations. **Recommendations and hints.** The system can prompt when conditions are suitable for a run or recommend changing parameters if data quality degrades.

Archiving and reproducibility. The parameters and context of each experiment are automatically recorded, increasing the reproducibility of results.

Technical implementation and model training

Learning on historical data. Archives of past runs, error logs, telemetry, and experimental results are used.

Hybrid approaches. Often combine physical models (beam motion equations, optics, system dynamics) with machine learning: Artificial intelligence adjusts parameters or compensates for unaccounted effects.

Attention mechanisms and multimodality. Attention-based architectures, which identify the most significant signals among multiple sensors and data channels, are useful for data analysis and control tasks.

The second section of the article describes the integrated operational platform for the AI functionality. The third section examines the integration of intelligent models into the ring photon source for controlling the setup and conducting experiments. The fourth section examines the role of intelligent models in experiments. The fifth section of the article provides an example of using the Stanford AI assistant in experiments.

Integrated operational platform with AI functionality

An integrated operational platform that integrates information from multiple disparate sources, creates a unified picture of current events, and provides tools for analysis, planning, and decision-making. The main problem addressed by the platform is not so much the lack of information as its fragmentation. The platform utilizes dozens of individual modules: information on equipment and personnel of researchers. Some information is received in real time, while others exist in the form of documents, tables, photographs, video recordings, or operator messages.

The core of the platform is a dynamic Ontology linked to a semantic object knowledge base and smart data.[8] The ontology can be thought of as a digital model of the real world, which contains data on all encountered objects, their equipment composition, and data on the objects' connections. All of this is constantly being refined, changed, and updated—an entire world in miniature. At the same time, the system maintains the distinction between fact, assumption, and the analyst's decision. A radar blip remains an isolated observation. The result of a photographic recognition is stored as the model's output with a defined probability. A researcher's lab affiliation can be an analytical assessment of a person. All this information is consolidated in an object card, and its origin and reliability level remain visible. This approach allows the system to move from storing individual messages to forming a holistic model of the environment.

Work environment that displays a comprehensive picture of the environment. Externally, it resembles a developed map, but each symbol on it is linked to an Ontology object. The user sees not just a mark, but an object with an observation history, documents, connections, photographs, and available actions. It supports collaboration: several operators at different locations see the same environment and can mark it in real time.

Module that organizes all observations on a single timeline is responsible for the time factor. This is especially important when working with moving objects. The user can see the route, direction and speed of movement, locations of stops, and the time of the last confirmed observation. If information was received from different sensors, the platform combines it into a common time sequence, but retains information about each individual source.

Graph allows for the study of relationships between objects. It allows you to see the structure, the subordination of its parts, affiliation, and the connections between parts, objects, and events. This allows you to analyze not only specific objects but also the structure of which they are a part. As a result, the system helps you understand which elements are truly important for the overall research organization.

Preparation of observed events, reports, orders, and plans. This is not a typical text editor. The document is linked to the Ontology and can automatically retrieve current information from it: if an object's parameters or status change, the information will update automatically, rather than becoming outdated paper.

Research support at all stages: from the initial stage to approval, execution, and evaluation of the results. Essentially, this is a digital implementation of the classic targeting cycle (find, record, track, assign, analyze, evaluate).

All functional components work with the same Ontology objects. The researcher does not need to manually transfer the same information between multiple programs. AI allows you to connect computer vision models, machine learning algorithms, large language models, and software agents to data and the Ontology. AI expands the platform's capabilities. AI operates through the Ontology and a set of enabled functions, and every action is logged. In practice, it works something like this: an AI assistant based on LLM (GPT, Claude, Gemini, etc.) sift through a colossal amount of information. Special assistants are based on dedicated hardware and consume an unlimited number of tokens. Thus, AI becomes a very powerful tool in the hands of an analyst. It can identify weaknesses and collect information. The more powerful the AI assistants become, the more powerful this research tool becomes. Firstly, the researcher has a constantly learning digital copy of the research process. Secondly, such systems can only be grown. Thirdly, AI here is an amplifier. It amplifies exactly what is already there. It turns well-structured data into an advantage.

Embedding artificial intelligence in a ring photon source

The Ring Photon Source is a megascience facility, a synchrotron radiation source where scientists conduct experiments and obtain highly accurate data on the structure of matter and rapid processes at the atomic level. During operation, the Ring Photon Source stations generate enormous data streams (detector signals, images, spectra, time series). Embedded intelligent models are needed to allow researchers to quickly process the data and see a clear picture of what's happening in real time:

Rapid signal interpretation. Artificial intelligence immediately translates detector readings into understandable metrics (e.g., "crystal structure is changing," "a new phase of matter is emerging").

Highlighting anomalies and interesting events. Rare or unexpected effects that would be easily missed during manual review are automatically flagged. Data compression and prioritization. A quick decision is made on what to save in detail and what to save in a simplified form to avoid overloading storage.

Decision support. The researcher receives prompts: "try changing the angle/energy/delay time," because the model detects trends.

Built-in model functions

Spectral-semantic interpretation. The neural network compares the current spectrum/diffraction pattern with a database of known states of matter and produces a concise summary: "a transition from phase A to phase B is observed," "impurity X has been detected."

Spatio-temporal reconstruction. A dynamic picture of the process (e.g., crack growth, diffusion, chemical reaction) is constructed from a series of frames/slices.

Attention mechanism for highlighting key areas. The attention mechanism helps the neural network focus on the most informative parts of a frame or spectrum, rather than treating everything equally. **Modality Conversion.** Translating spectral/wave data into understandable text descriptions and visual indicators (graphs, color maps) so that the researcher can quickly understand the system state.

Hybrid Models (Physical + Artificial Intelligence). The model relies not only on statistics but also on known physical laws (conservation of mass, symmetry, dispersion relations), which is important for scientific validity.

Information implementation

Real-Time Monitoring Dashboard: Left: raw data (spectrum, diffraction pattern), center: AI interpretation ("phase transition at time T", "anomalous peak at frequency F"), right: recommendations ("increase exposure", "change beam energy").

Automated Experiment Notes. Artificial intelligence generates a draft protocol: it records key events, parameters, timestamps, and anomalies.

Search for similar states. Based on the current spectrum/pattern, artificial intelligence finds previously observed similar processes in the archive and shows their outcomes.

Quantum technologies and objective reflection of experiments. SKIF data provide the most objective picture of the structure of matter at a fundamental level. Artificial intelligence here is a tool that helps the researcher see this picture reliably and quickly, without distorting it through interpretation.

Spectral and wave data. SKIF actively uses spectrometry and diffraction; spectral dictionaries and semantic neural networks are suitable for translating this data into understandable meanings.

Mental abilities and information perception. In this context, artificial intelligence acts as a "perception amplifier": it takes over the routine processing of large data streams, freeing the researcher's cognitive resources for understanding and formulating new hypotheses.

Technical implementation

SKIF's SCAUT software platform, as an experimental automation system, provides a unified interface for equipment control, measurements, and data analysis in real-life setups and simulations [9]. The platform is integrated with the control system.

Built-in intelligent models automate beam trajectory correction, parameter optimization, and beam property modification. This enables:

Edge computing near the detector. An intelligent model on the station's local server performs the initial processing and provides the researcher with meaningful metrics.

Centralized intelligent service. Specialized powerful models run on the center's computing cluster and provide in-depth analysis, recommendations, and archive search.

Integration with digital twins. The model predicts how the process will develop under new parameters and helps plan the next steps of the experiment.

The role of intelligent models in experiments

The role of intelligent models in experiments is growing dramatically. Artificial intelligence doesn't replace the researcher, but rather becomes a powerful assistant—it takes over routine tasks, identifies subtle patterns, and helps achieve results faster.

Let's look at a few specific examples where models are already showing results:

Automatic Spectra Processing. For example, a student at NSU developed a deep learning model for automatically interpreting X-ray photoelectron spectroscopy (XPS) spectra. The neural network searches for peaks and selects parameters, replacing manual work. **Synthetic data** is often used for training: spectra are simulated with noise, different peaks, and background, so the model learns to recognize real signals even in complex conditions.

Image Analysis. In X-ray tomography or other visualization methods, models help highlight objects, segment structures, and detect anomalies or subtle details that are easily missed by the naked eye. * **Experiment optimization.** Models can analyze previous results and suggest how to change setup parameters (beam energy, exposure time, detector settings) to obtain clearer data or test a specific hypothesis.

Pattern identification. Artificial intelligence can find hidden correlations between the properties of a substance and the characteristics of its interaction with radiation, which leads to new scientific hypotheses.

Predictive modeling. Models are sometimes used to simulate processes before a real experiment: for example, to predict how a substance will behave under irradiation and to plan the task.

Model effectiveness

Data quality and volume. Large, well-labeled datasets are required for training. A common problem is that real experimental data is scarce, so synthetic data generation is often used.

Interpretability.** In complex models, it can be difficult to understand why the model made a particular decision. This is critical for science: scientists need not only to obtain an answer but also to understand the logic behind it in order to physically test it.

Workflow Integration. The model must integrate seamlessly into the experimental pipeline: correctly read data from detectors, operate in real time (if necessary), and not hinder the overall research flow.

Physically Informed Learning. A good approach is to incorporate known physical laws and constraints into the model architecture. Such “Physics-Informed Neural Networks” (PINNs) produce more meaningful and reliable results.

Model Training. Model training is a symbiotic relationship: the setup provides unique data, which the models are trained on in conjunction with the developer’s data. Researchers’ innovative freedom is ensured for every field of activity by deep learning of intelligent supervised models for their safe and ethical creation and application in a specific area of research and activity. The supervised learning process filters out invalid data.

Data quality is important in model training and testing. Data collection and preparation takes up to 80% of the time. Prepare data for training, setting parameters (validation) and quality assessment (testing) of the model. Supervised models learn from examples. Vectors describing the environment under study are supplied to the input of the teacher and the trained model. The teacher gives the desired response. After training the model, the quality corrector compares its response with the correct response from the teacher and determines the error. Using an optimization algorithm, it adjusts model parameters to minimize the error of the trained model.

For different types of problems, appropriate models and algorithms are used. Linear algorithms predict quantitative values, for example, speed - distance. Logistic algorithms predict the probability of an event, such as the probability of obtaining an outcome. Support vector machine predicts types, classes and other categories based on analogy and similarity.

Data features are determined by ensembles of decision trees. Their simplicity and completeness provide a more accurate and stable solution. The metrics accuracy and recall determine the quality of the model. Accuracy measures the percentage of correct predictions. Completeness determines the proportion of objects of the desired category that are correctly identified by the model. Sometimes harmonious accuracy and completeness are used as a metric.

This approach ensures the safe, optimal, and ethical development and application of intelligent models across a variety of fields. Optimization of time, computing power, and resources enables a broad range of research opportunities.

Stanford AI agent learns to prepare X-ray experiments: A step toward manually tuned laboratories

Researchers from Stanford University and the SLAC National Accelerator Laboratory tested whether an AI agent can prepare an experiment at a synchrotron—a massive scientific facility where electrons are accelerated to produce extremely bright X-rays. This radiation is used to study the atomic structure of materials, molecules, and biological samples. The AI agent is capable of preparing synchrotron X-ray experiments. Specifically, the agent can independently align single-crystal samples on the synchrotron’s X-ray lines. The AI monitors detector images, experimental logs, and scan results through specialized software tools, analyzes the current state of the experiment, and generates instrument control commands to complete sample alignment (Figure 1). The work was demonstrated in a real experiment at the BL17-2 line of the Stanford Synchrotron Radiation Lightsource (SSRL).

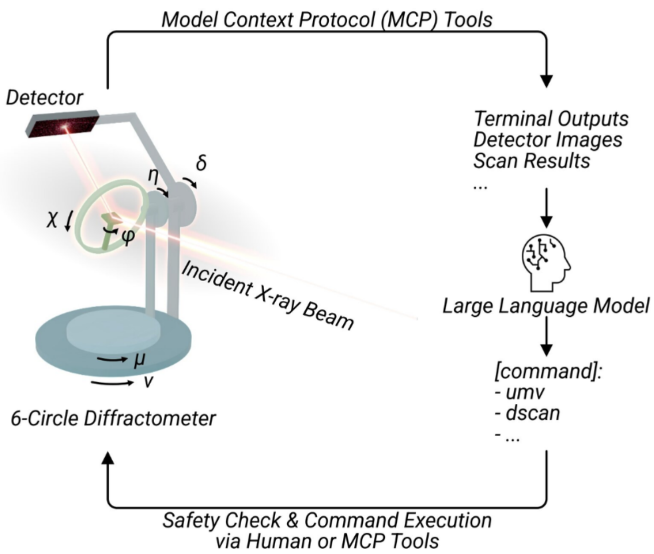

Figure 1 General workflow of an X-ray research AI.

This is an important step toward more autonomous scientific laboratories. The AI receives data on the state of the experiment, analyzes what’s happening, decides what needs to be done next, and moves the experiment toward its goal.

AI gained access to the experiment

In this project, the agent gained access to a set of experimental tools: it could read experiment logs, obtain images from the detector, perform motor scans, and analyze the state of the setup. One of the developers, Zhangtao Chen, explained that tools allow the AI to interact with the real world, and a properly written instruction explains how to use these tools. In the case of the synchrotron, the “real world” is the experimental setup. The AI sees the data, understands the context, decides what needs to be done next, and generates control commands for the setup. This is similar to the work of a scientific assistant, who doesn't just look at a screen but can suggest the next step and execute it using the available commands.

Language models

A unique feature of large language models is their ability to work with context. If given new observations, they can restructure their response based on this information. This is especially important in experimental physics, where unexpected situations are common. Traditional automation requires thinking through a huge number of scenarios in advance: if the signal is one way, we do one thing; if it's another way, we do another; if the device behaves strangely, we do something else. A real experiment is too complex to manually pre-program all possible cases. An AI agent can act more flexibly. It receives data, evaluates the state of the experiment, and chooses a path forward not only according to a rigidly defined scenario, but also taking into account the current situation. Such systems require verification, constraints, secure interfaces, and clear rules. The demonstration shows that AI can be useful in complex scientific settings.

Virtual line in front of a real synchrotron

One of the key parts of the work is the use of a virtual X-ray line. Synchrotrons are large and highly sought-after scientific facilities. Time at these facilities is pre-booked, and access is difficult. Therefore, developing an AI agent directly on a real device from scratch would have been virtually impossible. Therefore, the researchers first created a virtual experimental environment—a kind of synchrotron line simulator. In this digital environment, the AI could train, practice its workflow, and learn to perform a task without risking the real equipment or wasting precious time on the actual facility. This agent-based workflow was then transferred to the actual line. According to the researchers, only minimal changes to the input and output formats were required. If digital twins can be created for scientific instruments, the AI could train in advance in a simulation and then assist in real experiments. This way, labs can develop AI skills not directly on a real device, but in a safe virtual replica.

The work of Chen and his colleagues paves the way for the wider use of AI agents in scientific labs. In the future, such systems could automate routine operations at large research facilities, assist in experiment planning, respond more quickly to changes, and even perform certain types of measurements almost autonomously. This is especially important for facilities where time is limited and expensive. If AI can reduce preparation, reduce errors, and bring experiments to a working state more quickly, this will give researchers more time for what matters most—obtaining and interpreting scientific data. The authors extend this approach to many experimental tasks in biology and physics laboratories in general.

Conclusion

The ring photon source operates like a super-powerful X-ray microscope: it allows not only the examination of atomic structure but also the observation of processes in real time.

The extreme brightness and coherence of the beam allow scientists to penetrate matter at the atomic level. Using a ring photon source with integrated intelligent models, scientists can study:

* the structure of organic and inorganic substances (in chemistry and materials science);

* the dynamics of fast processes (e.g., crack formation, detonation, and the performance of materials at high temperatures);

* biological objects (the structure of proteins, macromolecules, and the interaction of drugs with biotargets);

* the properties of catalysts, microelectronic components, and nanomaterials.

The security of intelligent models is ensured by their application to every field of research and application. Innovative freedom of research is ensured by the use of specialized supervised deep learning models.

As experience accumulates and methods develop, the role of intelligent assistants in ring photon source experiments will only grow, reducing research time by tens and hundreds of times.

Significant potential also lies in attracting specialists from various fields of modern science, training qualified researchers skilled in SR experimental techniques, and establishing SR specializations at universities and institutes.[10–12] Synchrotron radiation is the tool of the future. And this future has already arrived.

Acknowledgements

None.

Conflicts of interest

There are no conflicts of interest.

References

1. Nikiforov D, Fedorov V, Levichev AE, et al. Commissioning of the SRF SKIF injector linear accelerator. Radiation detection technology and methods. 2026.
2. Evgeny Bryndin. Neural network axiomatic solver coaching agi method for solving scientific and practical problems. *American Journal of Mathematical and Computer Modelling.* 2025;10(4):110–120.
3. Evgeny Bryndin. Automated Analytics by Models of Brain based on big information and artificial intelligence. *Journal of Artificial Intelligence and Emerging Technologies*. 2025;6:7–16.
4. Bryndin E. Modality in format of harmonics of synergetic processes and cycles of nature. *International Robotics & Automation Journal.* 2026;12(1):54–62.
5. Evgeny Bryndin. Spatial generative multimodal dynamic AGI as model of consciousness. *Journal of Artificial Intelligence and Emerging Technologies.* 2026;3(2):1–12.
6. Evgenii Brindin. Swarm artificial intelligence in healthcare and medicine. *Far East Journal of Experimental and Theoretical Artificial Intelligence.* 2026;8(1):63–74.
7. Evgeny Bryndin. Spectral semantic analytics of local spaces with neural network models. *Innovation in Science and Technology.* 2026;5(2):58–68.
8. Evgeny Bryndin. Network training by generative AI assistant of personal adaptive ethical semantic and active ontology. *International Journal of Intelligent Information Systems*. 2025;14(2):20–25.
9. Nikiforov D, Fedorov V, Levichev AE, et al. SCAUT: A platform for automated beam tuning and diagnostics at the SKIF linear accelerator. *J INSTRUMENT MAKING*. 2026;21(7).
10. Mikhailin V. Synchrotron radiation in spectroscopy: A Textbook — 2nd Edition, Corrected and supplemented — Moscow: University Book; 2011. 164 p.
11. Avdzeiko OA. Synchrotrons and synchrotron radiation in physics teaching. TSPU Tomsk, 2025.
12. Kataev SG, Minich AS, Sadieva MS. Modern synchrotron methods at megascience sources for research and teaching of natural sciences. Advanced Training Program. TSPU Tomsk; 2026.