



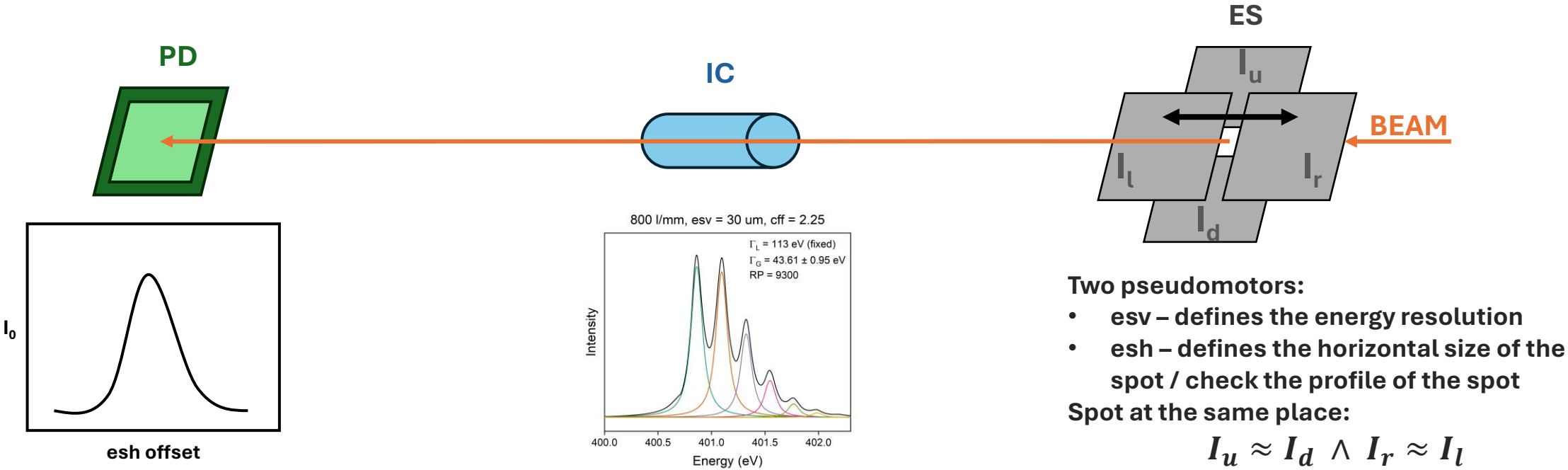
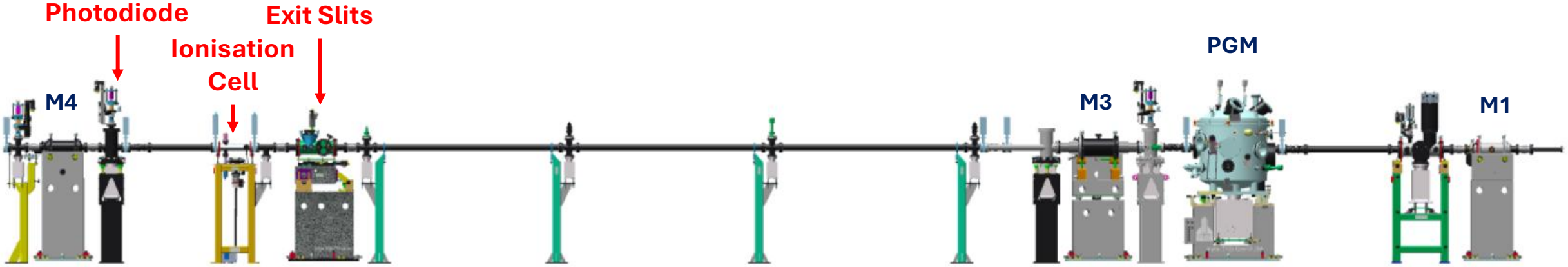
SOLARIS
NATIONAL SYNCHROTRON
RADIATION CENTRE

Leveraging AI and ML for assisted experiments, data analysis and virtual agents

Magdalena Szczepanik

on behalf of SOLARIS Team

Machine Learning-Based Beam Optimization



Virtual Assistant for Scientific and Operational Support

Challenges:

- High entry threshold in some departments
- High entry threshold for users from Poland who have never conducted research at a synchrotron
- Beamtime sessions are short, making it difficult to both learn the technical intricacies of the beamline and simultaneously maximize the time for producing valuable data
- Numerous internal regulations related to university administration
- A vast amount of manuals, technical documentation, and procedures
- A large number of requests submitted to the control systems department for simple tasks, GUI adjustments, or minor configuration changes, which places a heavy burden on a team already struggling with staffing issues

...It's easy to feel overwhelmed!

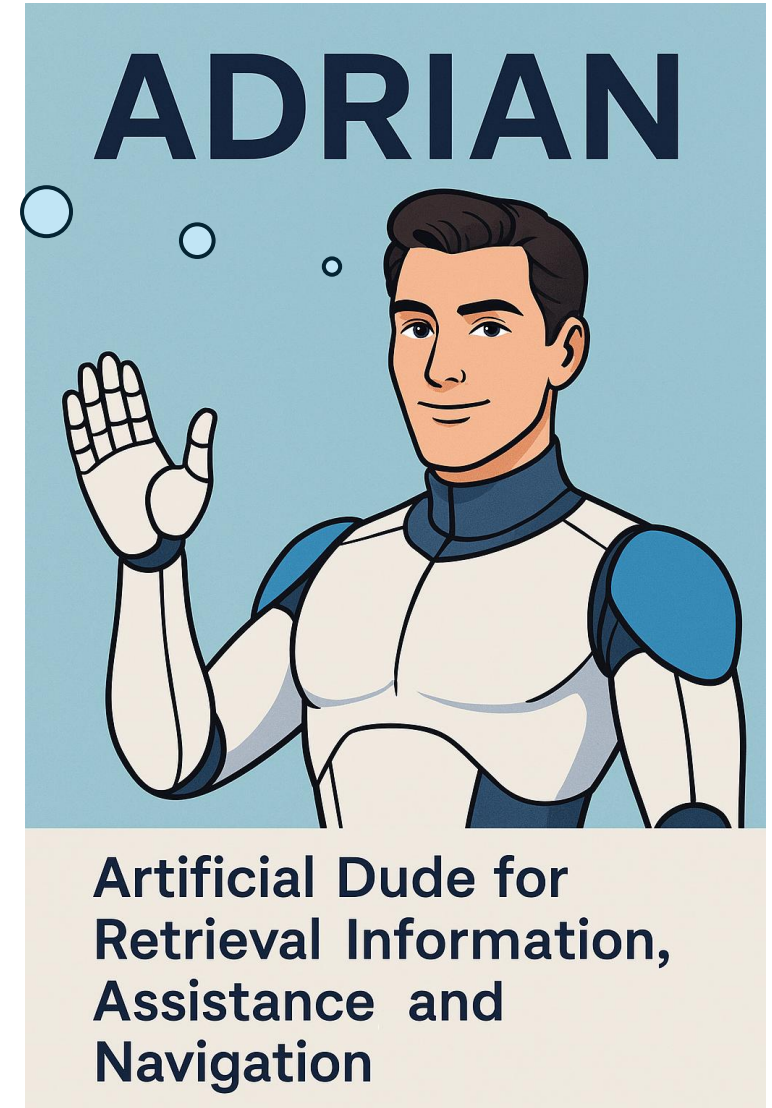
Virtual Assistant for Scientific and Operational Support

Challenges:

- High entry threshold in some departments
- High entry threshold for users from Poland who have never conducted research at a synchrotron
- Beamtime sessions are short, making it difficult to both learn the technical intricacies of the beamline and simultaneously maximize the time for producing valuable data
- Numerous internal regulations related to university administration
- A vast amount of manuals, technical documentation, and procedures
- A large number of requests submitted to the control systems department for simple tasks, GUI adjustments, or minor configuration changes, which places a heavy burden on a team already struggling with staffing issues

...It's easy to feel overwhelmed!

Hi, how can I make
your life more
bearable?

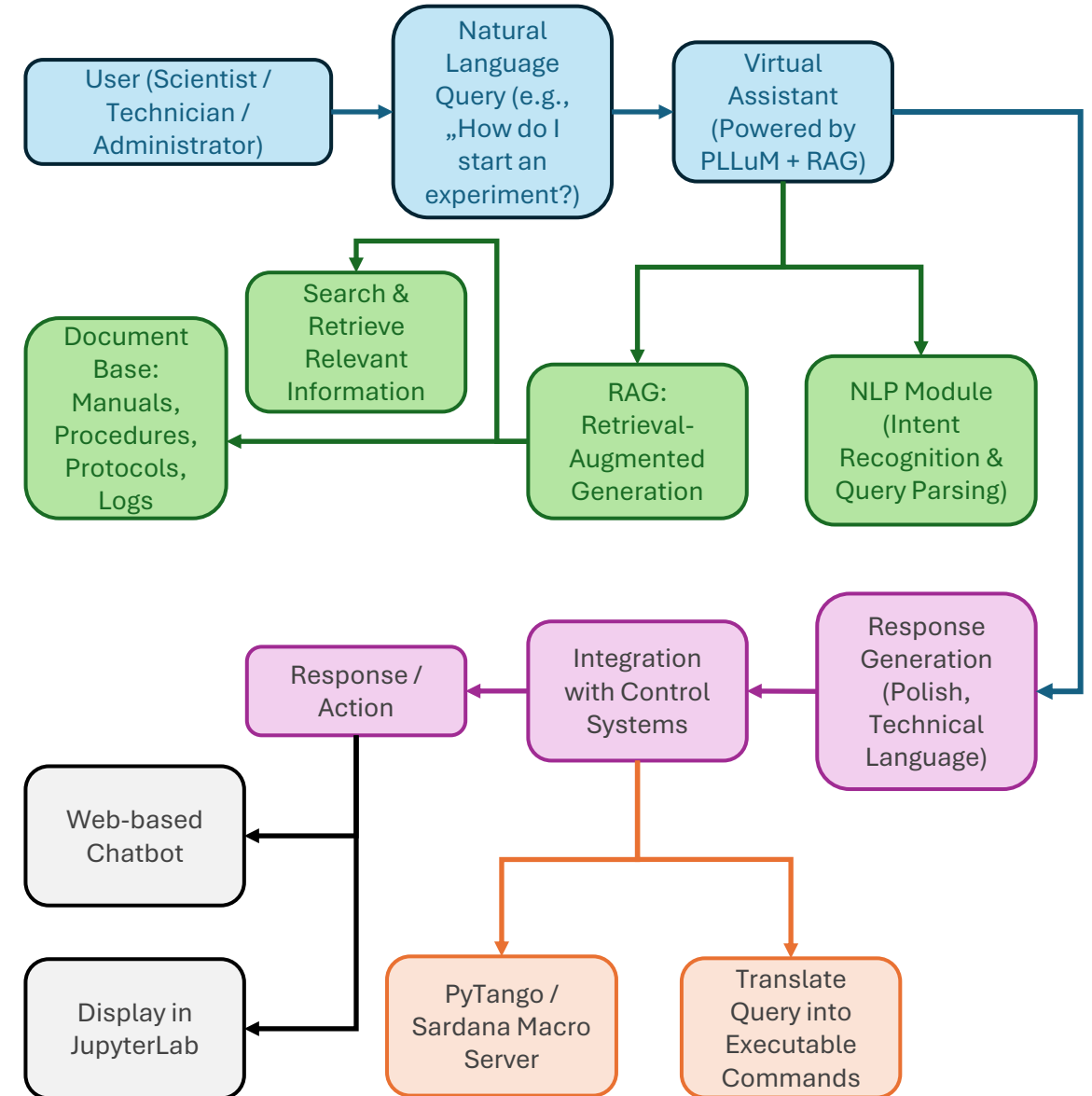


Virtual Assistant for Scientific and Operational Support

Challenges:

- High entry threshold in some departments
- High entry threshold for users from Poland who have never conducted research at a synchrotron
- Beamtime sessions are short, making it difficult to both learn the technical intricacies of the beamline and simultaneously maximize the time for producing valuable data
- Numerous internal regulations related to university administration
- A vast amount of manuals, technical documentation, and procedures
- A large number of requests submitted to the control systems department for simple tasks, GUI adjustments, or minor configuration changes, which places a heavy burden on a team already struggling with staffing issues

...It's easy to feel overwhelmed!





Leveraging AI and ML for assisted experiments, data analysis and virtual agents

M. Szczepanik¹, M. Piekarski¹, M. Fafowski¹

¹National Synchrotron Radiation Centre SOLARIS, Jagiellonian University, Kraków, Poland



What is this poster about?

This poster presents two conceptual initiatives developed at the SOLARIS synchrotron facility:

- Machine learning-based beamline optimization
- A virtual assistant powered by large language models (LLMs)

Both approaches aim to improve experimental precision, operational efficiency, and user accessibility.

Fun Facts about SOLARIS

- First of Its Kind** - SOLARIS is the first synchrotron facility in Poland and the only one in Central-Eastern Europe!
- Inspired by Literature** - The name SOLARIS comes from the famous novel by Stanisław Lem, which explores the mystery of an alien ocean capable of materializing human memories and emotions – an allegory of the limits of human understanding and communication.
- Science Meets Play** - SOLARIS actively promotes science outreach. As part of this mission, it created an educational board game available, helping players explore the world of synchrotron science in a fun and interactive way.
- Opera in the Synchrotron** - In a unique cultural event, the experimental hall of SOLARIS hosted a performance of the opera "Solaris" as part of the Opera RARA festival – merging science and art in a truly spectacular setting.

Machine Learning-Based Beam Optimization

Beamlines at SOLARIS employ multiple mirrors and monochromators forming a complex optical path that requires precise alignment. A proposed machine learning-based approach is being considered to address two main goals:

- Beam Quality Enhancement** – maximizing intensity, spatial focus, and energy resolution using signals from a soft X-ray photodiode.
- Beam Position Stabilization** – maintaining consistent beam alignment on the sample, monitored via induced current on exit slit blades.

Due to physical constraints, these signals cannot be acquired simultaneously; therefore, the concept involves two independent ML models. The first would predict optimal mirror and monochromator settings for beam quality, while the second would compensate for energy-dependent shifts to stabilize beam position. Both models are intended to be integrated with the existing Tango Controls and Sardana framework, running on AlmaLinux 9, and developed in Python using libraries such as scikit-learn and PyTorch. The envisioned training strategy combines offline initialization with online incremental updates, leveraging historical and real-time data. Model inference is planned to occur during measurement cycles, enabling adaptive optimization without manual intervention. This approach is expected to improve experimental reproducibility, reduce alignment time, and support more complex protocols.



Acknowledgements

The National Synchrotron Radiation Centre SOLARIS is supported by the Ministry of Science and Higher Education of the Republic of Poland under contract no. 1/SOL/2021/2.

Background and Literature Overview

Recent advances in artificial intelligence are reshaping beamline control and diagnostics. Research increasingly shows that AI can enhance precision, automation, and user interaction in synchrotron facilities.

Morris et al. [1] introduced a Bayesian optimization framework for autonomous beamline alignment, capable of navigating complex parameter spaces with minimal prior input. In a follow-up study [2], they showed that online learning techniques outperform traditional methods in speed and accuracy, enabling real-time optimization. Rebuffi et al. [3] developed an AI system for aligning nanofocusing mirrors using digital twins and wavefront sensing, achieving sub-micron precision. Xie et al. [4] applied deep learning to estimate alignment errors in Kirkpatrick-Baez mirrors, demonstrating that convolutional neural networks can extract meaningful features from speckle-modulated X-ray images. Mathur et al. [5] introduced VISION, a modular AI assistant that enables natural language interaction with beamline systems, simplifying experiment setup and control.

Inspired by these developments, SOLARIS is exploring similar AI-based approaches to enable autonomous tuning of its beamlines. The aim is to improve throughput and reproducibility by reducing manual intervention and optimizing performance in real time.

In parallel, SOLARIS is evaluating PLLuM (Polish Large Language Universal Model), a family of transformer-based models developed by Polish research institutions [6][7]. Trained on over 100 billion Polish-language tokens, PLLuM generates accurate, context-aware responses across scientific, technical, and administrative domains. Its support for Retrieval-Augmented Generation (RAG) allows access to external knowledge bases and document repositories – essential for interpreting manuals, safety protocols, procurement rules, and experimental logs.

Virtual Assistant for Scientific and Operational Support

The SOLARIS synchrotron hosts numerous research groups from across Poland, many of whom are new to synchrotron techniques and unfamiliar with beamline operation. This creates a need for intuitive, accessible support systems to guide users through complex instrumentation and workflows. A virtual assistant is being conceptualized to support scientists, technical staff, and administrative personnel through intelligent, natural language interaction across multiple domains:

- Scientific Support** – assisting researchers in configuring and running experiments, interpreting procedures, and interacting with control systems.
- Technical Assistance** – providing quick access to manuals, safety protocols, and troubleshooting guides to reduce cognitive load and improve efficiency.
- Administrative Help** – supporting staff with procurement regulations, internal documentation, and compliance-related queries.

The assistant is envisioned to integrate with the existing Tango Controls and Sardana frameworks, using LangChain or similar tools to implement Retrieval-Augmented Generation (RAG). This would enable dynamic access to internal documentation repositories. Secure deployment with role-based access control and LDAP authentication is planned to ensure data protection. A prototype is intended to be tested on one beamline before potential scaling across the facility. This initiative aims to improve reproducibility, accessibility, and autonomy in synchrotron research, while lowering the entry barrier for new users and enhancing the overall user experience at SOLARIS.



Conclusion

SOLARIS is exploring the integration of machine learning and large language models to enhance beamline operations and user support. These AI-driven tools are intended to improve experimental precision, reduce manual workload, and make advanced instrumentation more accessible.

References

[1] T. W. Morris et al., "General Bayesian algorithm for the autonomous alignment of beamlines," *J. Synchrotron Radiat.*, vol. 31, no. 6, pp. 1461–1466, Nov. 2024.

[2] T. Morris et al., "On-line optimization of synchrotron beamline using machine learning," in *Optical System Alignment, Telemetry, and Verification XIV*, SPIE, Oct. 2023.

[3] L. Rebuffi et al., "Autofocus: AI-driven alignment of nanofocusing X-ray mirror systems," *Opt. Express*, vol. 31, no. 34, p. 30204, Nov. 2023.

[4] J. H. Xie et al., "Deep learning for estimation of Kirkpatrick-Baez mirror alignment errors," *Nuclear Science and Technology*, vol. 34, no. 8, p. 122, Aug. 2021.

[5] S. Mathur et al., "VISION: A modular AI assistant for natural language interaction in scientific user facilities," *Math. Learn. Sci. Technol.*, vol. 4, no. 3, p. 102021, Jan. 2025.

[6] "PLLuM: Polish Large Language Model - Artificial Intelligence." Accessed: Sep. 06, 2025. <https://pmlm.com/en/what-is-polish-large-language-model-artificial-intelligence>

[7] "PLLuM: A Family of Polish Large Language Models." Accessed: Sep. 06, 2025. <https://huggingface.co/CYFRIA/2025/PLLuM-12B-hf>

Any advices or suggestions? Let's meet: WEPD089