

ELI BEAMLINES VIRTUAL LAB: PILOT IN NON-DESTRUCTIVE METHODS FOR HERITAGE TESTING

M. Greplová Žáková¹

V. Kantarelou¹, A. Zymaková¹, M. Přeček¹, A. Morabito¹, U. Chaulagain¹, L. Giuffrida¹

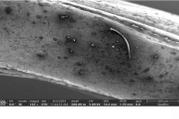
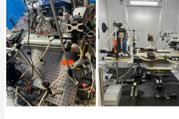
¹The Extreme Light Infrastructure ERIC, ELI Beamlines Facility, Za Radnicí 835, Dolní Břežany, 252 41, Czech Republic

CONCEPT OF VIRTUAL LAB SOFTWARE

- Virtual Lab will be a digital platform integrating several non-destructive analytical methods already available at ELI Beamlines. These techniques currently exist at different Technology Readiness and Commercial Readiness Levels (TRLs and CRLs); the Virtual Lab will therefore serve as a unifying environment supporting their further development, organization, and future commercialization.
- Heritage artefacts will serve as demonstration examples within the project. However, the concept of the Virtual Lab SW will be designed as a general and expandable framework, easily adaptable to other analytical methods or services with commercialization potential which already are or will be available at ELI Beamlines (or potentially ELI ERIC), such as optical coating or VR Beamline services.

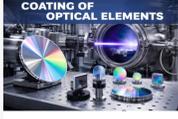


VIRTUAL LAB
ELI BEAMLINES
Pilot: Non-destructive heritage testing
TACR SIGMA 2026-2027

| | | | | |
|--|---|--|--|--|
|  <p>SEM+EDS Biolab Representative: Martin Přeček ThermoFisher (SEM) with Quorum (cryo module) ELIBIO 2019-2022</p> |  <p>XES X-ray tube, shielded hutch S2 Representative: Anna Zymaková The first non-destructive detection of Pt inclusions in gold matrix (Celtic coins), [2] TRANSFER VOUCHER (SIC) 2025</p> |  <p>XRF X-ray tube, shielded hutch in E4 Representative: Vasiliki Kantarelou TRANSFER VOUCHER (SIC) 2026</p> |  <p>PIXE, DPAA laser-accelerated protons, ELIMAIA-ELIMED, L3 HAPLS Representatives: Martina Greplová Žáková, Vasiliki Kantarelou Experiment PIXE: Prague City Museum, L3-E4 beamtime (ELIMED), May 2026 OP PRAGUE 2019 - 2022 TRANSFER VOUCHER (SIC) 2026</p> |  <p>X-ray Tomography E5 hall Representative: Antonia Morabito First step: studying fragments of glass beads (→ manufacturing technique) - current energy 20-50 keV - laser-driven X-ray source MERIT</p> |
|--|---|--|--|--|

And then?

A versatile modular solution designed to enable the future integration of additional methods or services after the Virtual Lab 'Heritage Pilot' phase.



COATING OF OPTICAL ELEMENTS
? Optical coating
Optical Lab, ELI Beamlines
Precise and thin coating of optical elements or other relevant components



VR Beamline
? VR Beamline
Virtual Reality Beamline (VRL) is an interactive web-based platform developed at ELI Beamlines that enables intuitive visualization of complex laser-plasma simulations, and in the future, experimental data as well. The platform supports use in a standard web browser with a monitor, as well as a fully immersive Virtual Reality (VR) mode with a VR head-mounted display.

THE ROLE OF SCIENTIFIC CONSULTANT

- Many stakeholders in art, archaeology, and cultural heritage do not possess detailed knowledge of advanced analytical techniques and may be uncertain about how best to investigate their objects. The Scientific Consultant addresses this gap and, as a paid service, prepares a report by translating the client's question into clear scientific objectives and proposing an optimal analytical strategy, including appropriate techniques, their sequence, and any necessary sample preparation. If the customer proceeds with the recommended analytical workflow, the cost of the report will be deducted from the final service price. In addition, the Scientific Consultant will guide the client throughout the entire analytical process, from the initial clarification of needs to the final interpretation of results.
- The uniqueness of the service lies in combining deep expertise in advanced physical methods with a fundamental understanding of the application domain, enabling the Virtual Lab to transform complex analytical capabilities into a coherent, decision-oriented solution tailored to each client. Rather than delivering isolated technical reports, the Scientific Consultant synthesizes results across multiple techniques, explains findings in accessible language alongside technical detail, clearly states uncertainties and limitations, and directly links conclusions to the client's underlying question.

FINAL GOAL

- Virtual Lab concept:**
By the end of the project, we will demonstrate a commercially viable beta version of the Virtual Lab software enabling customer-oriented access to advanced non-destructive analytical methods.
- Functionality and content:**
The Virtual Lab will provide a functional, tested online environment presenting the portfolio of available methods and stations, including their advantages and limitations. It will support measurement scheduling and ordering, sharing and commenting on results, and communication with users. This will be complemented by station documentation and workflows in order to enabling standard measurements to be performed by operators or students in the future.
- Technical readiness and security:**
The system will operate on dedicated ELI Beamlines cloud infrastructure, applying relevant cybersecurity measures, multi-level authentication, and other critical protections against cyber threats.
- Readiness level advancement:**
The project will advance the Virtual Lab from TRL 2 to TRL 5–6 and from CRL 2 to CRL 5. Backend documentation will enable routine operation by trained staff and serve as knowledge maps supporting future development, funding planning, and preparation for commercial use.
- Market engagement:**
Although broad commercial orders will not yet be feasible, the project will expand the network of partners and potential customers, actively involving them in further development of the stations and in shaping additional Virtual Lab services and functionalities.



SW PLATFORM - VERSATILE AND MODULAR UPGRADE OF LABTIDY

The Virtual Lab will be an online software platform developed on the LabTidy [1] core and operated on ELI BL cloud infrastructure. It combines elements of a LIMS, ELN, service management (Research and User Portal), external methods & instruments portfolio, internal workflow description & station documentation, and expert consulting to design, coordinate, order, and interpret multi-method analytical testing of heritage artefacts in its pilot phase.

Main functionalities:

- Portfolio of methods and stations
- Measurement scheduling and ordering
- Availability calendar
- Sharing and commenting on results, online editing, and communication with users
- Internal station documentation and workflows enabling standard measurements to be performed by operators/students in the future
- Role-based permissions and custom notifications

* LabTidy software was developed at the Institute of Physics of the Czech Academy of Sciences (IoP CAS) and has been successfully used for commercial orders since 2016 by the Crystallography Laboratory of IoP CAS and the Institute of Macromolecular Chemistry of CAS.



VALIDATION OF COMMERCIAL POTENTIAL (EXTERNAL)

| Market potential for key segments | | | | | Sector | | | | |
|-------------------------------------|----------|--------|-------------------------------|--|-----------------------------------|----------|--------|-------------------------------|---|
| Sector | Location | Market | Projected market (EUR m) 2030 | Summary | Sector | Location | Market | Projected market (EUR m) 2030 | Summary |
| Art and archaeology | EU | TAM | 2 500 | The art and archaeology market represents a specialized, high-value niche for advanced material analysis. The EU TAM is estimated at EUR 2.6bn by 2030. The primary driver for this market is the need for authentication, provenance research, and conservation of cultural heritage artefacts. The Virtual Lab services are crucial for non-destructive analysis of materials. The SAM for specialized analytical services is estimated at EUR 350m in the EU for 2030. The SOM is projected to grow from to EUR 15m by 2030, reflecting the increasing adoption of scientific methods in art history and archaeological research. | Energy and environmental sciences | EU | TAM | 13 274 | The energy and environmental sciences market is the largest segment, with an EU TAM EUR 13bn in 2030. This market is driven by stringent environmental regulations, the need for pollution monitoring, and the development of new energy technologies. The Virtual Lab's services are crucial for trace element analysis, contamination assessment, and regulatory compliance. The EU SAM for material characterization in this sector is estimated at EUR 25 in the EU for 2030. The SOM is projected to grow to EUR 12m by 2030, making it the largest obtainable market for the Virtual Lab. |
| | | SAM | 300 | | | | SAM | 2 818 | |
| | | SOM | 11 | | | | SOM | 112 | |
| | | SOM | 7 430 | | | | SOM | 18 614 | |
| Material science and nanotechnology | Global | TAM | 1 114 | This segment is characterized by rapid innovation and a strong demand for precise material characterization. The market is driven by the development of new materials, advancements in nanotechnology, and the need for quality control in manufacturing processes. The Virtual Lab's services are essential for R&D, failure analysis, and quality assurance. The SAM for advanced characterization techniques is estimated at EUR 344 in the EU for 2030. The SOM is projected to grow to EUR 37m by 2030. | Pharmacy and chemical industry | EU | TAM | 3 831 | The pharmaceutical and chemical industry is a stable and highly regulated market. The global TAM for maintenance analytical testing services is estimated at EUR 114 in 2030. The market is driven by the need for quality control, regulatory compliance (e.g., Good Laboratory Practice), and R&D in drug development and chemical manufacturing. The Virtual Lab's services are essential for elemental analysis, impurity profiling, and material characterization. The SAM for these services is estimated at EUR 30 for 2030. The SOM is projected to grow to EUR 100m by 2030, offering a consistent and growing revenue stream. |
| | | SAM | 744 | | | | SAM | 1 149 | |
| | | SOM | 37 | | | | SOM | 34 | |
| | | SOM | 6 206 | | | | SOM | 11 125 | |
| SAM | 2 482 | SAM | 3 337 | | | | | | |
| SOM | 114 | SOM | 100 | | | | | | |

Typical customers (pilot phase): museums (historians, archaeologists, restorers), galleries, universities, private collectors, auction houses, banks, and insurance companies, ...

COOPERATION



REFERENCES

- [1] LabTidy – a web-based Laboratory Information Management System (LIMS); <https://www.labtidy.com>
- [2] Zymakova, Anna, et al. "A fast-integrated x-ray emission spectrometer dedicated to the investigation of Pt presence in gold Celtic coins (3rd–1st century BCE)." *X-Ray Spectrometry* 52.6 (2023): 401–411.