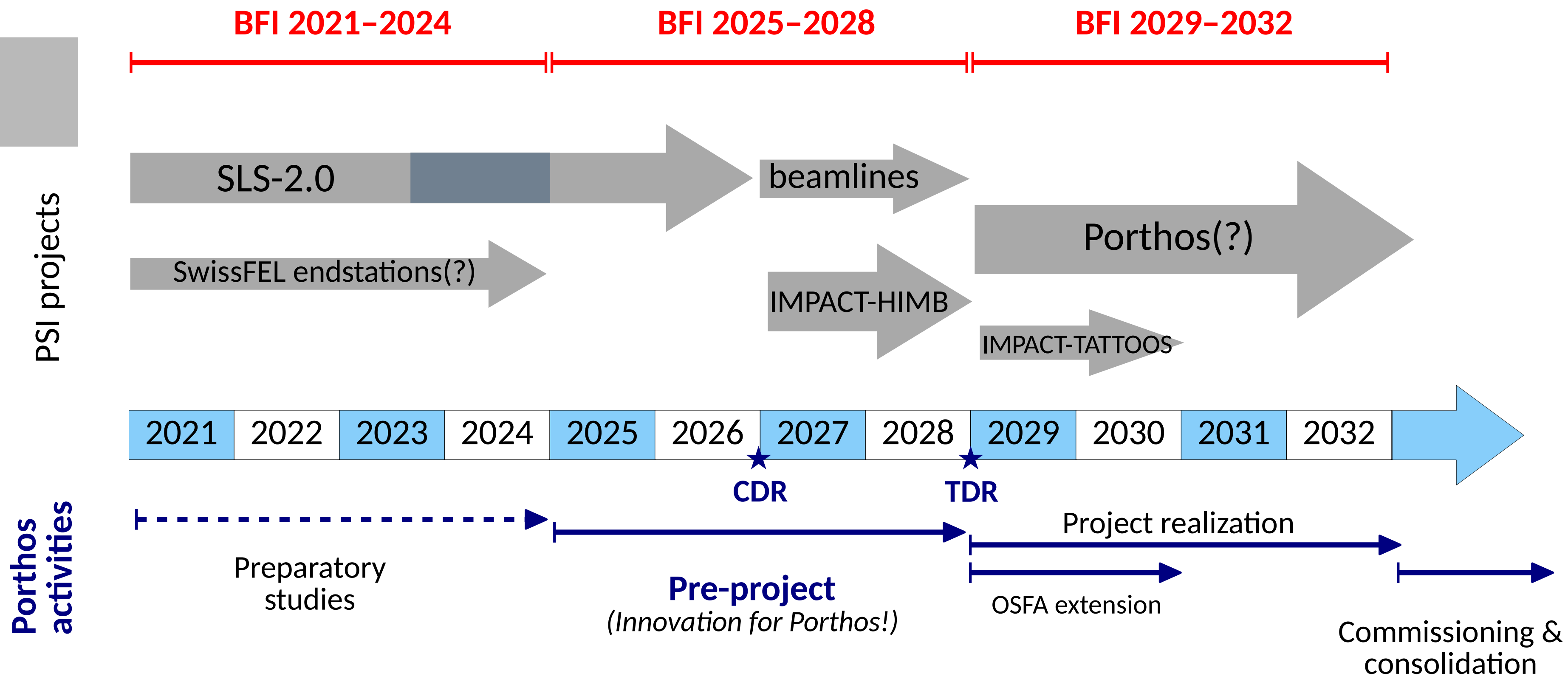
PAUL SCHERRER INSTITUT
PSI

Thomas Schietinger :: Paul Scherrer Institut

Porthos preproject options: status and outlook

Porthos Working Group, 2 December 2022

Reminder: Porthos timeline



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“Pre-announcement” for Roadmap 2027 submitted to ETH Board

ETH BOARD

Strategic Planning 2025-2028 of the ETH Board for the ETH Domain
Proposal for a Research Infrastructure --- PRE-ANNOUNCEMENT FOR ROADMAP 2027

Name of the Research Infrastructure: ***Porthos – An advanced hard X-ray waveform generator***
Responsible Institution(s): ***Paul Scherrer Institut***
New research infrastructure ☐ / substantial upgrade of existing research infrastructure ☒

1. Summary

The ability to visualize the structure of matter and functioning of biological, chemical, and physical processes has been a fundamental driver of science and the resulting technological innovations. In the past decades, the frontier has moved towards ultrafast processes on the femto- to attosecond time scale, imaging structures with atomic resolution and following reactions with sensitivity to individual chemical elements. PSI has successfully set into user operation the hard X-ray branch Aramis at SwissFEL, with two running experimental stations and a third one being implemented while the soft X-ray branch Athos has been recently installed and first pilot experiments are scheduled. Knowledge gained during the design and realization of Aramis and Athos in combination with innovative accelerator concepts have paved the road to **the extension of SwissFEL to its third branch, Porthos, which will be unique in its conception as an advanced hard X-ray waveform generator with an expected paradigm-shifting impact** like that brought about by analogous optical and microwave signal generators. In fact, Porthos will produce sequences of very bright, hard coherent X-ray pulses (as short as 10^{-16} seconds) at a repetition rate of 100 Hz with full polarization control up to the Mössbauer gamma line (14.4 keV) and beyond. The increase of the electron beam energy will allow pushing the X-ray wavelength below 0.5 Å, i.e., half of the atomic radius, and will double the achievable energy range compared to Aramis (!), i.e., to the point where thicker experimental systems, including samples as well as their containers for *operando* studies, particularly relevant for the sustainability agenda, become accessible.

2. Strategic relevance

With the recently commissioned SwissFEL, delivering femtosecond pulses of soft, tender and hard X-rays at a repetition rate of 100 Hz, Switzerland has leveraged opportunities from the ultrafast community and the unique power of X-ray investigations for a broad range of scientific applications. Porthos will accomplish SwissFEL's original design concept, i.e., the provision of 9 world-class FEL endstations for science, medicine and engineering (corresponding to a 50% capacity increase compared to what Aramis and Athos can provide using the same linear accelerator), thereby strengthening Switzerland's leadership role as a worldwide key player in the field.

2.1. Scientific rationale and challenges

Porthos will significantly contribute addressing the grand challenges facing our society, from the development of smart/new materials and mitigation of climate change to fundamental aspects in infectious diseases and atomically resolved biochemical structures and processes. Applications will cover all science and engineering disciplines, from semiconductors for electronics, catalysis for chemical reactions, to lead molecules for drug development. Examples of key experiments are:

- **Life Sciences:** Structure determination through truly radiation-damage-free diffraction-before-destruction time-resolved crystallography, exploiting the envisaged short-pulse/high-power (SPHP) operation mode at very short wavelengths. This will be particularly appealing for tiny crystals, to better map rapid diffusion of small molecule ligands.
- **Novel materials for future technologies:** Non-linear operando X-ray spectroscopy at K-edges of several 4d transition metals via stimulated emission studies with chemical sensitivity and nonlinear transient grating X-ray spectroscopy, enabling new ways in inorganic chemistry, catalysis, and materials science, for example to measure momentum-dependent ultrafast demagnetization processes (spintronics) of key importance in the field of quantum and neuromorphic computing.
- **Quantum Technologies:** Time-domain interferometry in the hard X-ray regime, exploiting the expected tunability of the phase difference and relative amplitudes of two adjacent pulses provided by Porthos Mode-Locked Lasing (MLL) capabilities, resulting in the coherent control and readout of

quantum states, as well as highly precise and efficient measurements of electronic transition linewidths. Moreover, the q-range accessible with hard X-rays will allow the investigation of ultrafast charge and spin fluctuations on atomic length scales in novel quantum nanodevices.
- **Imaging**: Single-shot full-field and ptychographic imaging of ultrafast non-repeatable phenomena with single-digit nanometer spatial resolution in complex, operando conditions, perfectly complementing the imaging portfolio offered by SLS2.0.

2.2. Advantages for science and society

Porthos will enrich Switzerland's scientific landscape of tomorrow and will enable paradigm-shifting scientific progress. The first SwissFEL user publications reported on pioneering, high-impact experiments elucidating, among other things, the behaviour of ferric/ferrous heme proteins that play an important role in the respiratory function of hemoglobin, the dynamics of active transport across bio-membranes, and the functionality of organic light emitting diodes (LED). As described above, Porthos will produce harder X-rays with tailored pulses and expand the range of operation to be much closer to direct applications in all sectors. Moreover, the track records of the SLS and SwissFEL show that many technical innovations required to realize and continually advance cutting-edge facilities such as Porthos bear a large potential for commercial applications outside the project itself, and thereby become important innovation boosters for the ETH Domain and Switzerland.

2.3 Contribution to unique features of the ETH Domain

a) *Organisational embedding*

The project will be designed, constructed and operated by the PSD, GFA and LOG divisions of PSI following the matrix paradigm used also for the Athos undulator branch of SwissFEL and the upgrade SLS 2.0 of the Swiss Light Source. The execution of large-scale high-tech engineering projects for leading edge science is a feature of the ETH Domain shared by only a very small handful of international academic competitors such as Stanford (with SLAC) and the University of California (with the Lawrence Berkeley Laboratory). Strong links within the "campus" communities of ETHZ and EPFL as well as other national laboratories will be provided through joint faculty/staff appointments, shared studentships and other training programmes as well as collaborative user-driven research.

b) *Institutions involved*

The ETH Domain, Swiss academic units and Universities of Applied Sciences as well as major pharmaceutical companies and numerous SMEs will all benefit and capitalize on the new capabilities offered by Porthos. International organizations such as European XFEL and CERN are our long-term partners and will remain key collaborators during the upcoming decade.

3. Financial requirements (estimate) *** indicates PSI costs*

The current budget estimation foresees 100 MCHF investments for the machine and two endstations. In addition, construction costs of 40 MCHF have been estimated for extending the building in order to accommodate the new experimental areas. A first tranche of 10 MCHF will be borne by PSI in the 2025-2028 funding period to finance a "Pre-project" phase for the technical machine design as well as the advanced conceptual design for the endstations and the planning of the civil construction. The remaining 130 MCHF are requested for the 2029-2032 funding period and dedicated to the realization of the project.

Costs (MCHF)	2021-2024	**2025-2028**	2029-2032
Investment costs		10**	90
Operating costs			
Construction costs			40
Total costs		10**	130

Date: 6 April 2021

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Porthos preproject 2025–2028

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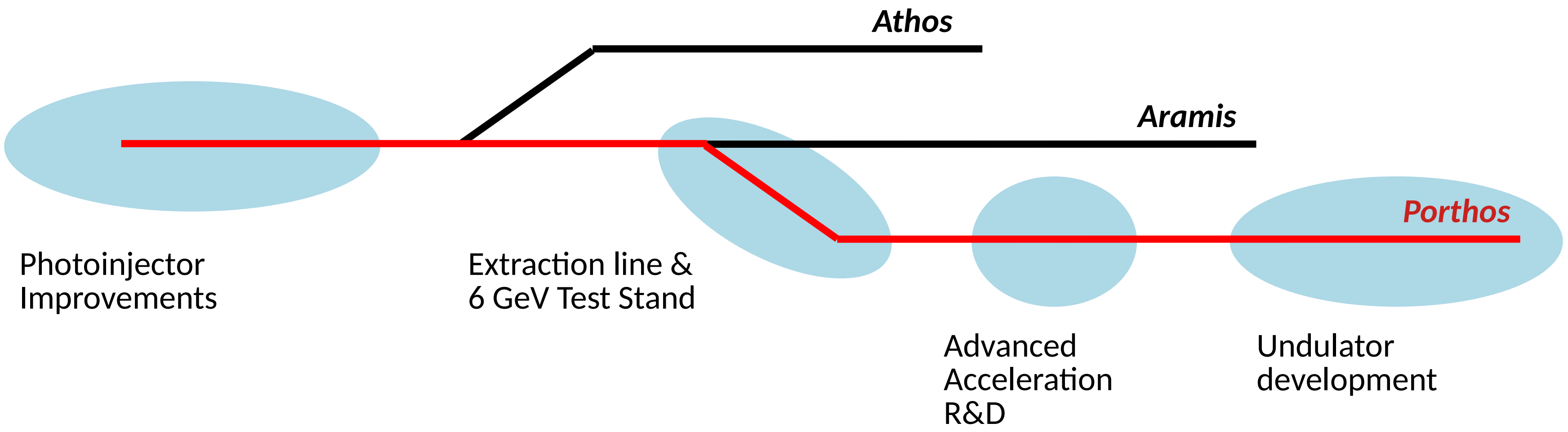
How to spend the 10 MCHF?

After discussion at SSB, PSAC and elsewhere, high-level agreement to pursue four main directions during the pre-project (emphasis on *innovation!*)



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Porthos preproject elements

Preproject Element	Scope	Preproject Objective (2025–2028)	Objective 2023 *(realistic!)*
Photoinjector Improvements	• **Electron gun test stand** • **Photoinjector design** • Installations in OSFA as far as possible	• Operational gun test stand • Photoinjector conceptual design (as part of Porthos CDR) • Installations in OSFA?	• Conceptual design for gun test stand • Preliminary photoinjector design evaluation
Extraction Line & 6-GeV Test Stand	• **Extraction line** • **6-GeV multipurpose test stand**	• Simplified extraction line completed • 6-GeV test stand used for Porthos component testing	• Possible test program for 6-GeV test stand • Concept for long-term test area (LTP?)
Undulator Development	• **Undulator type selection** • Hence: **Design undulator line** (including chicanes) • **Undulator prototype**	• Conceptual design undulator line (as part of Porthos CDR) • Operational undulator prototype	• Preliminary design(s) for undulator line • Quantitative basis for selection of undulator type
Advanced Acceleration R&D	• **Wakefield acceleration experiments** • **Computational verification** • **Potential use in SwissFEL**	• Completed R&D program on wakefield acceleration with dielectric structures • Conceptual ideas for potential use in SwissFEL (indep. of CDR)	• Measurement shifts (as far as time and resources allow) • Computational efforts

Thank you