

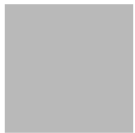
PAUL SCHERRER INSTITUT



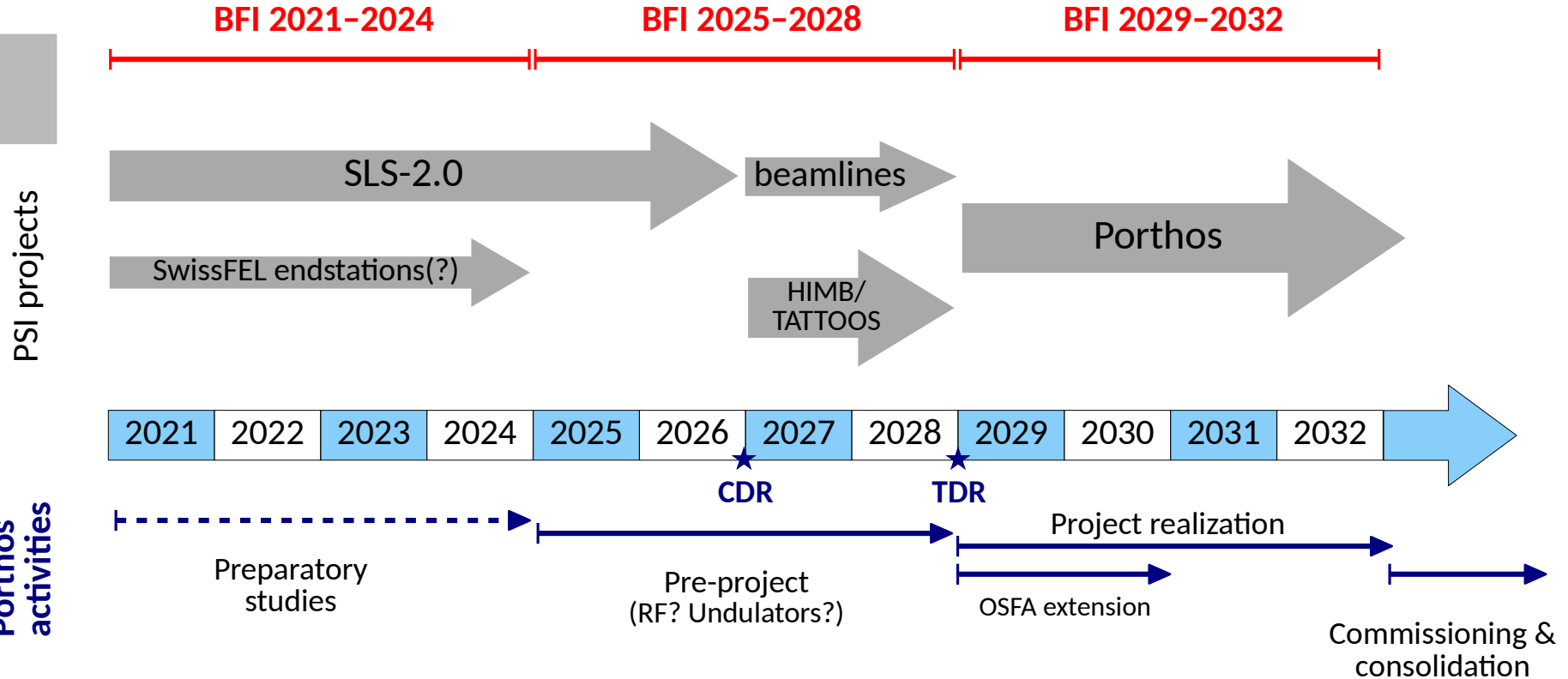
Thomas Schietinger :: Paul Scherrer Institut

Porthos Preproject 2025–2028

SwissFEL Porthos Working Group, 3 November 2021



New Porthos timeline



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^{-18} 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), 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			40
Construction costs			40
Total costs		10**	130

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

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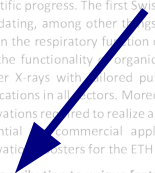
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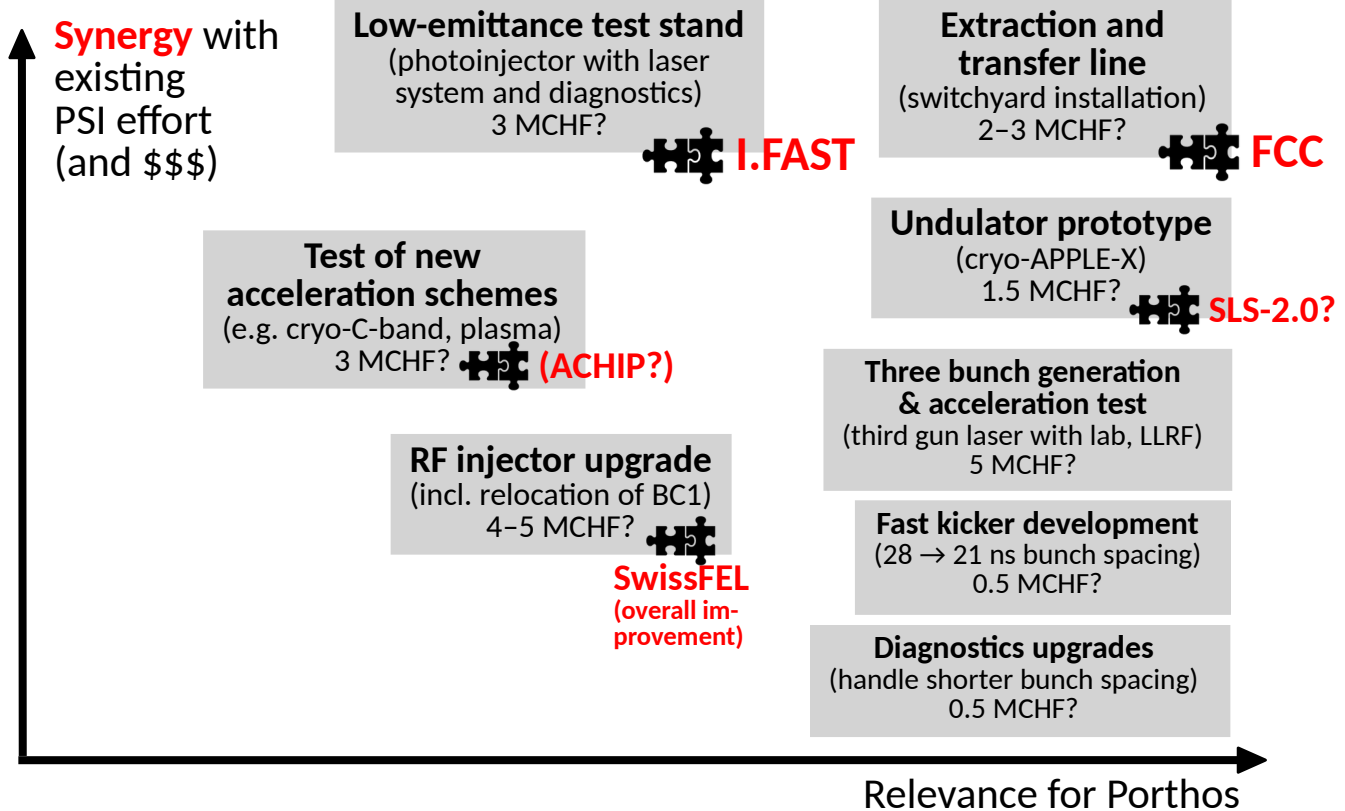
**Porthos
preproject
2025-2028**



“Pre-announcement”
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Porthos preproject: possible elements

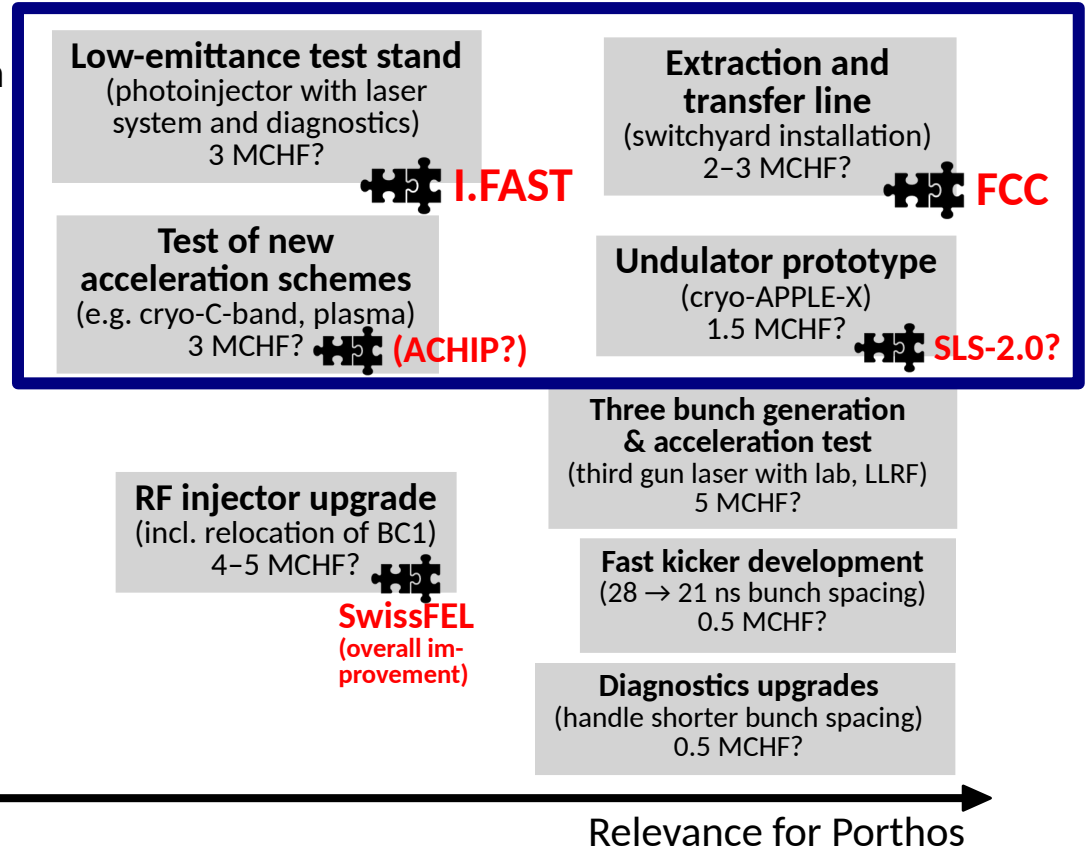
- Assume ~ 10 MCHF for pre-project:
→ 2 large items plus 1 - 2 smaller items?
- What are our priorities?
- Additional funding sources?



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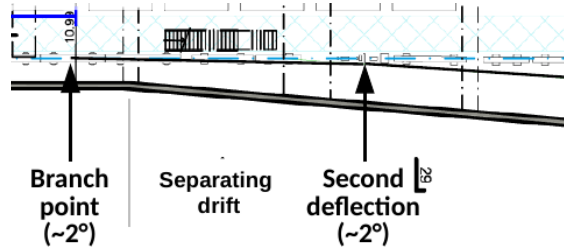
Synergy with existing PSI effort (and \$\$\$)



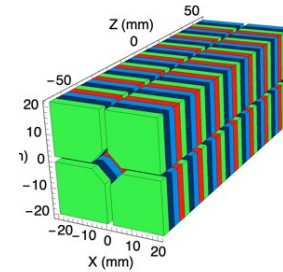
Relevance for Porthos

Porthos preproject: 4 main elements

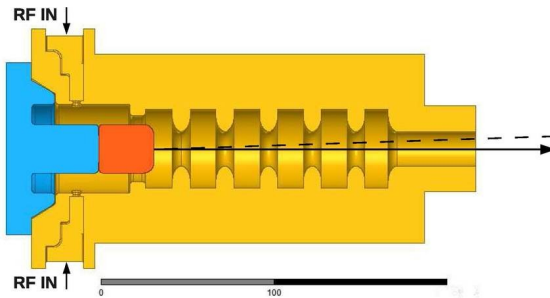
Extraction and transfer line



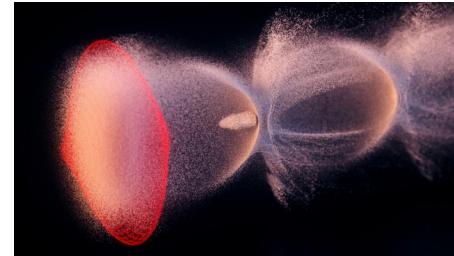
Undulator prototype



Ultra-low emittance gun



New acceleration schemes



Porthos preproject I: Extraction and transfer line

- **Main questions:**

- Cost/feasibility of an early realization (with dipole extraction)?
- Embedding in global Porthos project (rough design of the full line)
- Added value for Porthos to have an extraction line before project start
 - Test of Porthos diagnostics?
 - Test of Porthos undulator prototype?

- **Synergies** with other projects:

- P³ Project (Positron Production at PSI):
 - What is the mutual impact?
 - Can we realize/finance the extraction line even before the preproject?

- Brain storming leader: **Sven Reiche**

Porthos preproject II: Undulator prototype

- **Main questions:**

- Is cryo-APPLE-X really the undulator we want for Porthos?
- What is the state-of-the art worldwide for this technology?
- Which crucial properties do we need to verify with the prototype?
- Cost/feasibility of a prototype (location, cryogenics etc.)

- **Synergies** with other projects:

- SLS-2.0 undulators?
- Other labs?

- Brain storming leader: **Marco Calvi**

- **Main questions:**

- How can we lower the emittance at the gun even further? RF technologies, configurations,...
 - What is the ultimate limit?
- What will be the benefit for Porthos (achievable photon energy, FEL power etc.)?
- What will be the benefit for the other SwissFEL beamlines?
- How to deal with an ultra-low emittance beam (compression scheme, laser heater etc.)
- Cost/feasibility of a test stand with prototype gun at PSI?

- **Synergies** with other projects:

- I.FAST (Innovation Fostering in Accelerator Science and Technology)
 - EU Horizon 2020 programme May 2021 – April 2025
 - PSI participates with a C-band gun prototype

- Brain storming leader: **Simona Bettoni**

- **Main questions:**

- What are the options? Cryo-C-Band, Dielectric Laser Acceleration (DLA), plasma-wakefield acceleration (PWFA)?
- Cost versus benefit in view of the Porthos objectives?
- Cost/feasibility of a test stand?

- **Synergies** with other projects:

- EuPRAXIA (Mike via EPFL)
- CERN laser & plasma acceleration expert panel

- Brain storming leader: **Rasmus Ischebeck**

Thank you

