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STOCKHOLM-UPPSALA CENTRE FOR FREE ELECTRON LASER RESEARCH

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Compact

Consideration of the photon beamline design for CompactLight

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CompactLight Meeting, Helsinki, 2019

Motivation and Outline

"The key objective of CompactLight is to demonstrate, through a conceptual design, the feasibility of an innovative, compact and cost effective **FEL facility**."
*The beamline design is currently **not** included.*

The aims of this presentation are to introduce the basics of FEL beamlines and point out the need to consider the beamline design for CompactLight.

- A few more words about science requirements
- Purpose and key characteristics of the X-ray beamline
- Types and examples of beamlines
- Considerations of the beamline for CompactLight

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Science Requirements and Performance Specification for the CompactLight X-Ray Free-Electron Laser

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Target parameters

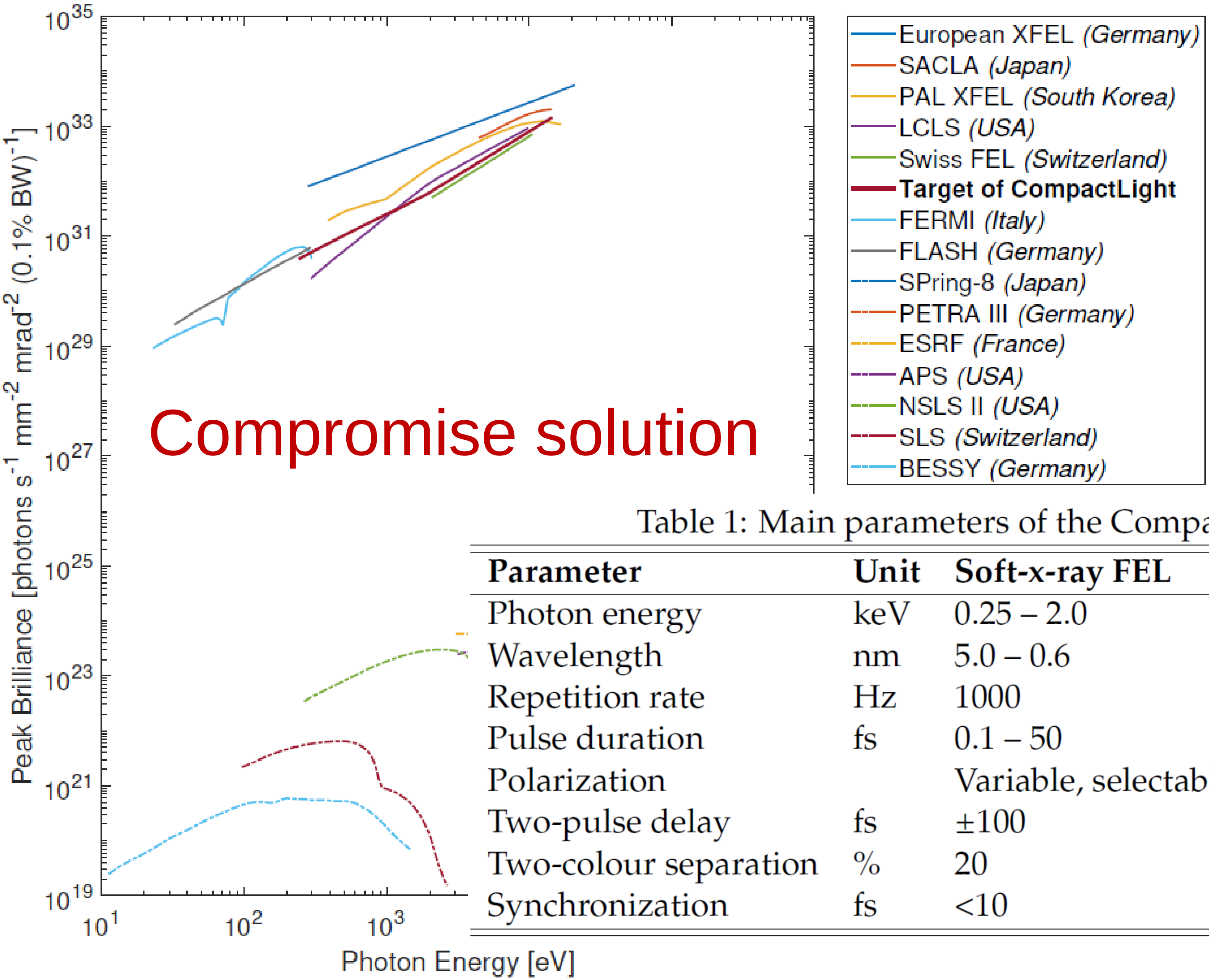


Table 1: Main parameters of the CompactLight FEL.

Parameter	Unit	Soft-x-ray FEL	Hard-x-ray FEL
Photon energy	keV	0.25 – 2.0	2.0 – 16.0
Wavelength	nm	5.0 – 0.6	0.6 – 0.08
Repetition rate	Hz	1000	100
Pulse duration	fs	0.1 – 50	1 – 50
Polarization		Variable, selectable	Variable, selectable
Two-pulse delay	fs	±100	±100
Two-colour separation	%	20	10
Synchronization	fs	<10	<10

Closer look at the user requests

Table 2: Photon characteristics specified by potential users in the online questionnaire. Blue columns correspond to diffraction or scattering experiments. Yellow columns correspond to spectroscopy. Orange columns correspond to interactions between x-ray and matter. Grey columns correspond to other experiments.

Min. photon energy [keV]	4.5	0.05	0.01	3	1	0.5	0.5	0.01	1	0.2	3	3	0.7	0.5	2	0.2
Max. photon energy [keV]	12.6	7	10	20	12	10	15	0.5	9	10	16	16	10	10	20	20
Repetition rate [Hz]	120	1000	100000	1.1		100	1000	100000000	120	1000000	1000000	4500000	100	10000	1000	1000000
Pulse energy [μJ]	100	250	100	1000	2000	1	5		3000	10000	2000	5000	10	10	10	100
RMS pulse energy stability [%]	20	10	10	0.1	1	10	1		10	10	10	10	10	0.1	0.01	5
Microfocus [μm]	1	1	0.5	10	0.1	10	5		1	0.1	1	0.25	100	100	10	30
Degree of transverse coherence [%]	100	80	100	80			100			90	80	80	100	100	30	10
Coherence time [fs]	1	2	0.2	1							2	10	1	100	50	10
RMS bandwidth [%]	0.05	20	10			0.01	0.01		0.3	0.3	0.5	0.2			10	10
FWHM pulse duration [fs]	10	2	0.2	50		40	10		60	1	50	10	50	10	100	500
Two-pulse spectral separation [nm]	0.6												0	0	100	100
Two-pulse temporal separation [fs]	100	150	10										0	100	10000	1000
Laser-FEL sync [fs]	10	10	1	300		40	10				200	30	50	10	10	5

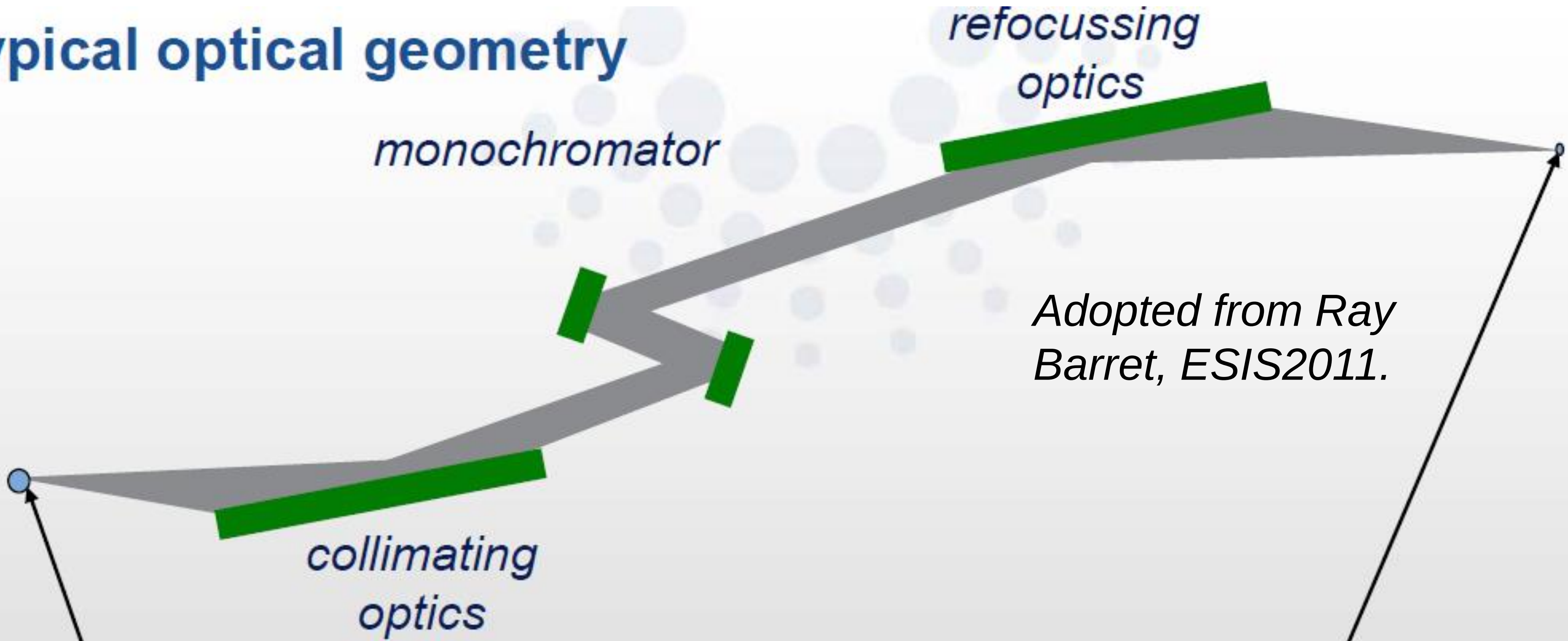
From the survey and discussions it was clear that users think in terms of two main modes of FEL operation:

- high photon energy resolution mode – spectroscopic mode
- high photon pulse energy mode – imaging mode

Having the requirement of two modes of operation can have, in fact, also implications on the undulator design.

Get "right" photons to the sample

Typical optical geometry



Adopted from Ray Barret, ESIS2011.

Source
- spectrum (ΔE/E)
- emittance (size x divergence)
- degree of spatial coherence
- brilliance (ph/s/mm^2/mrad^2/0.1%bw)
- polarisation (linear, circular, elliptic)

OPTICS ?

Sample
- beam size (μm)
- beam divergence (μrad)
- flux (ph/s)
- temporal coherence: ΔE/E
- spatial coherence
- polarisation

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High-resolution (mono) beamline

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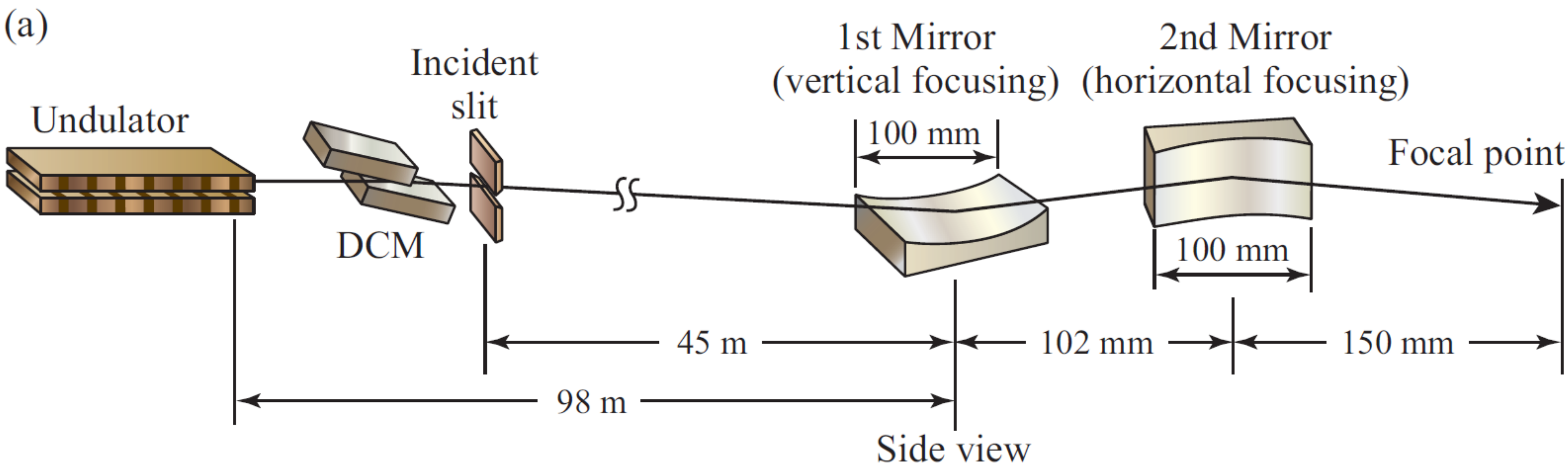
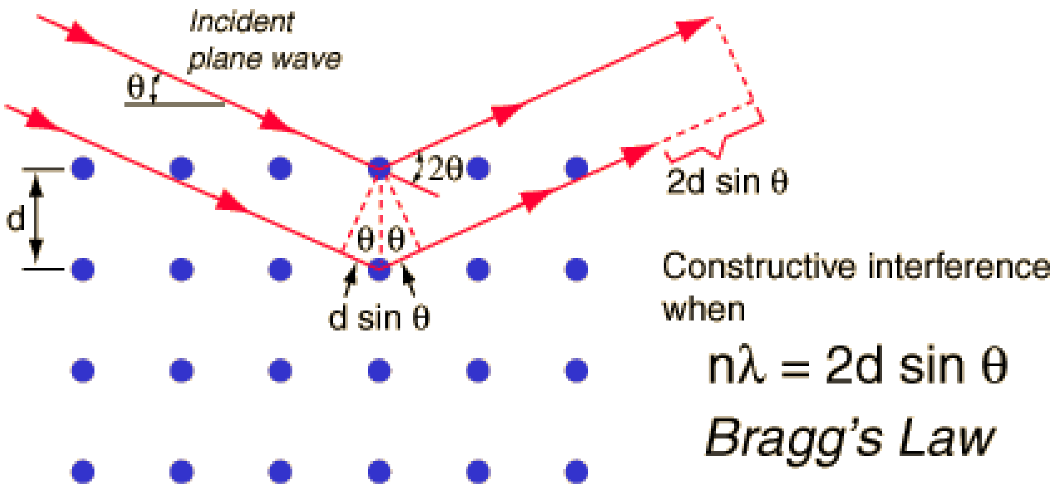
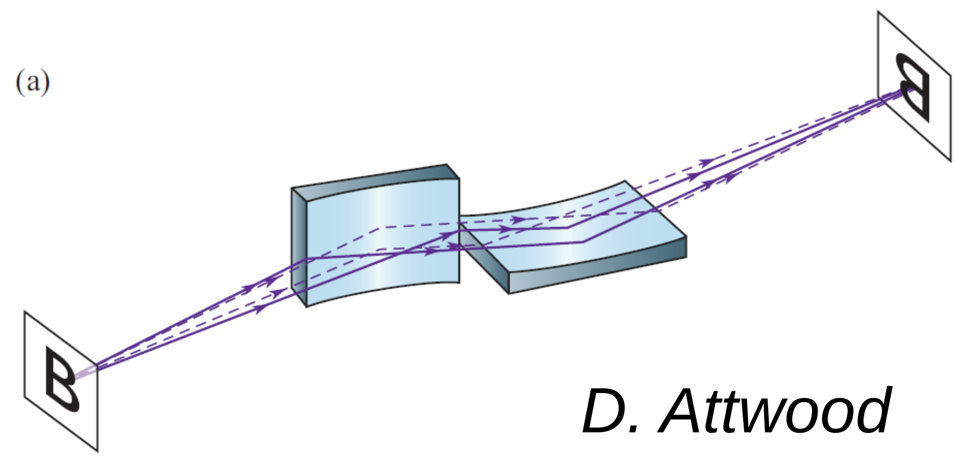


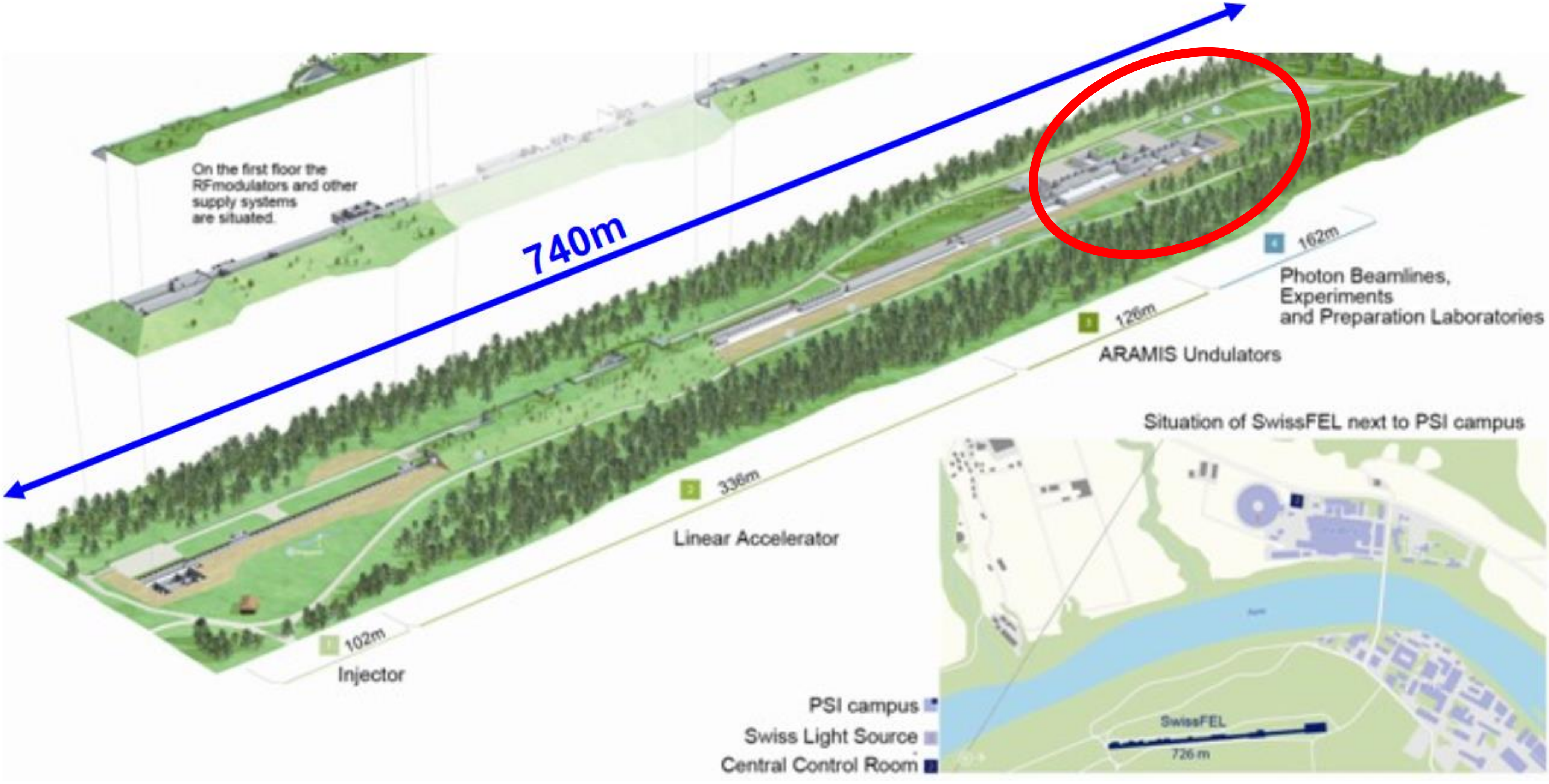
The crystal monochoromator makes use Bragg's diffraction whereas mirror reflection is based on total external reflection.





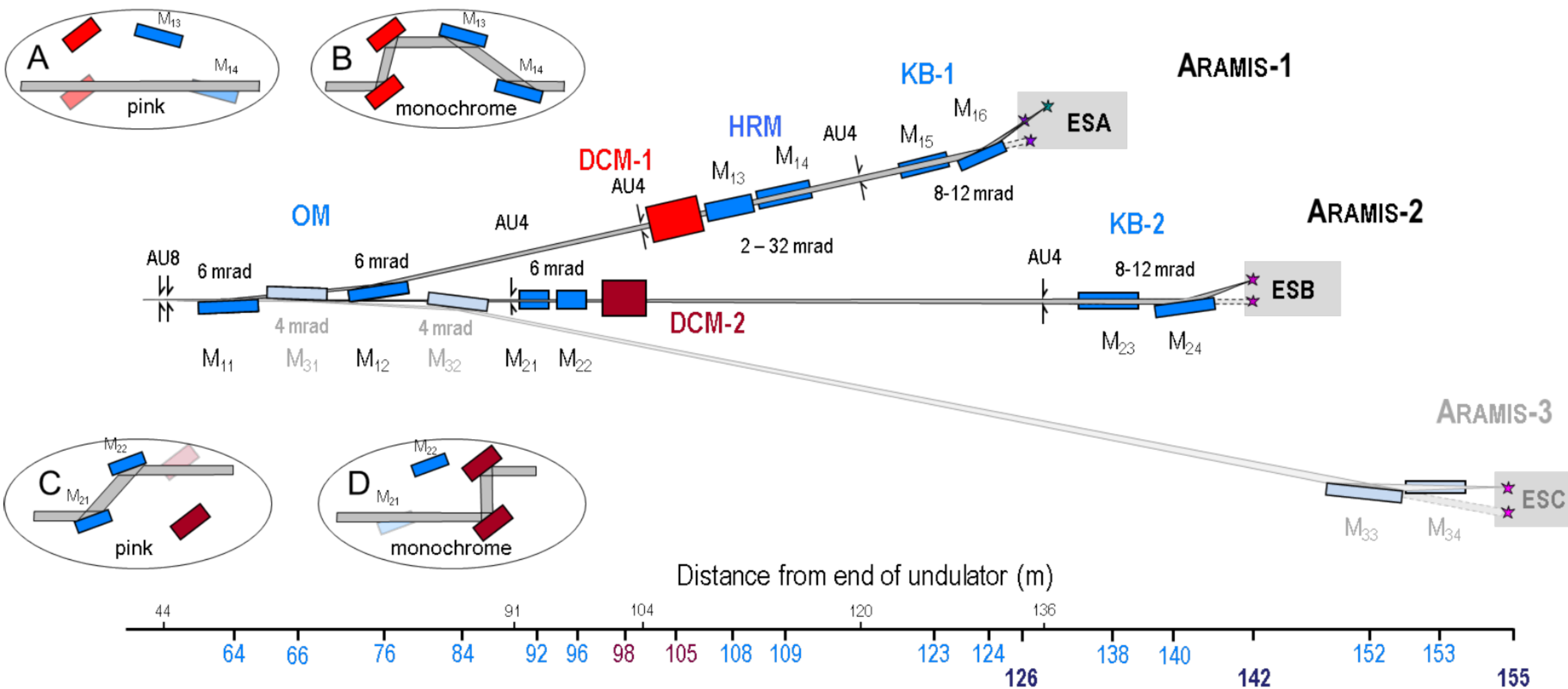
D. Attwood

Artistic view of Swiss FEL facility



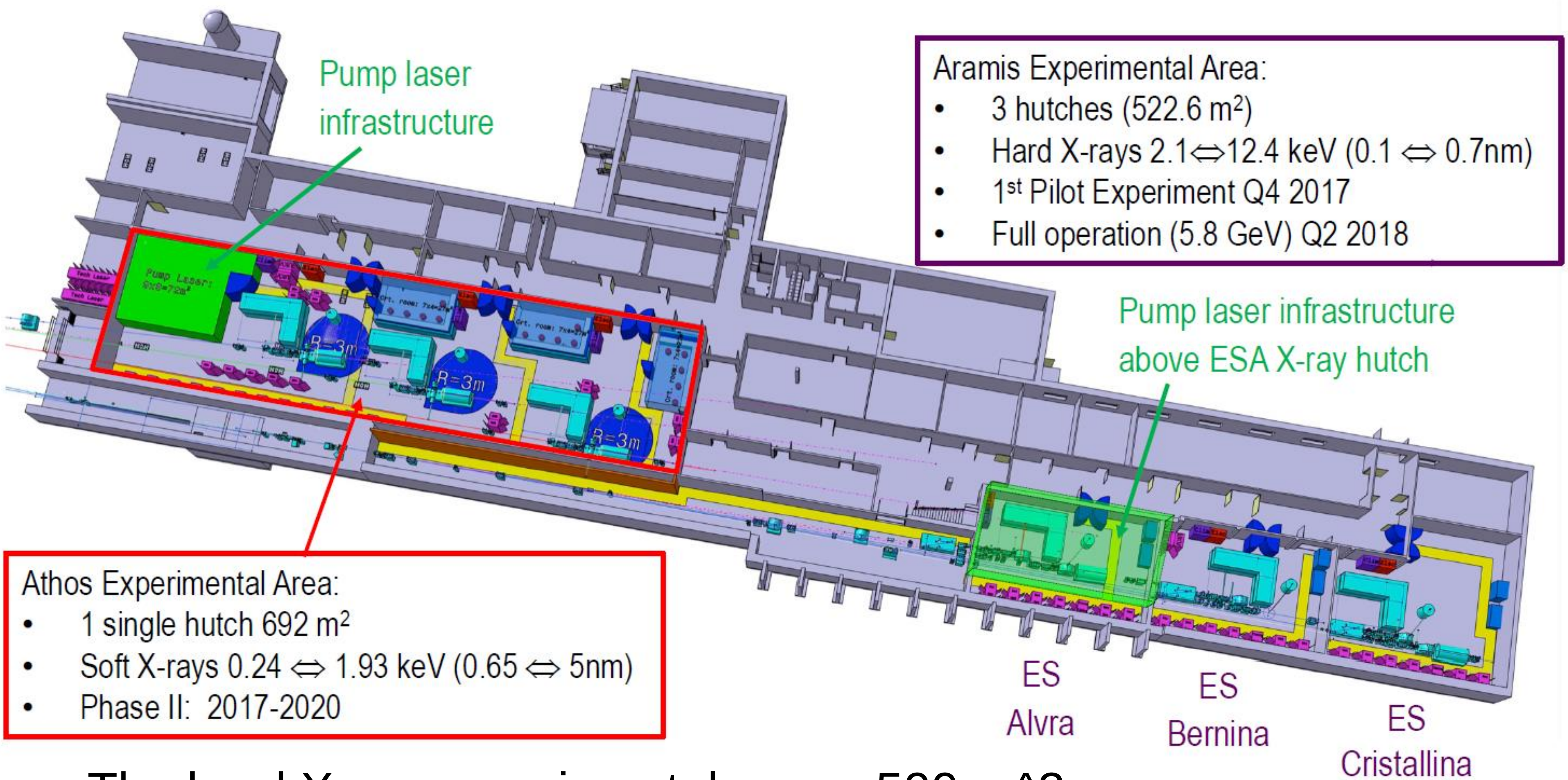
The X-ray beamline constitutes 15 % of the facility length.

Swiss FEL, hard X-ray beamline



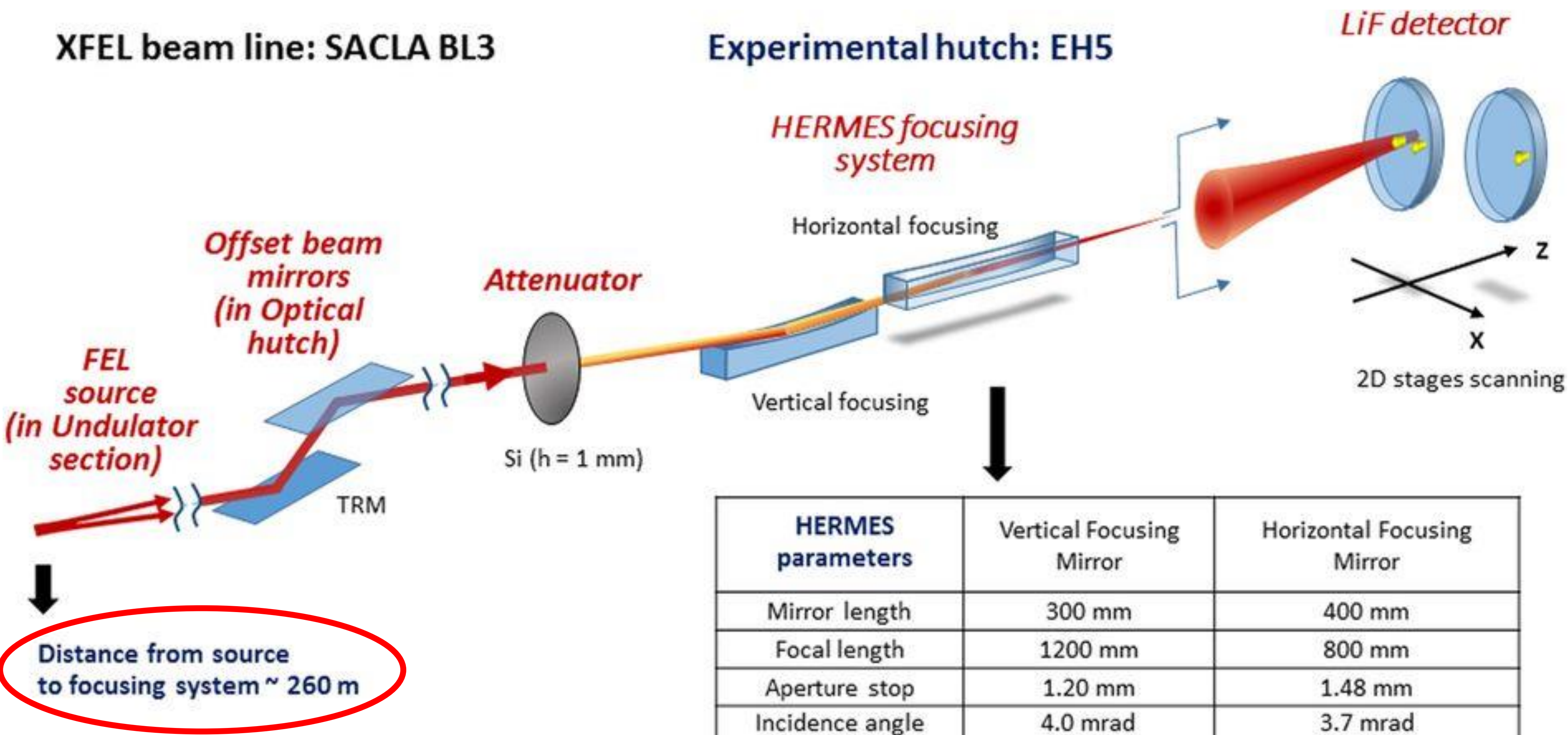
- The hard X-ray optical system Aramis is 110 meters long
- It has 2 +1 beamlines
- Each beamline can operate both in the mono and pink modes

Swiss FEL, experimental area



- The hard X-ray experimental area ~500 m^2
- The soft X-ray experimental area ~700 m^2
- Non-negligible impact on the total footprint of the FEL facility

SACLA FEL, optical system



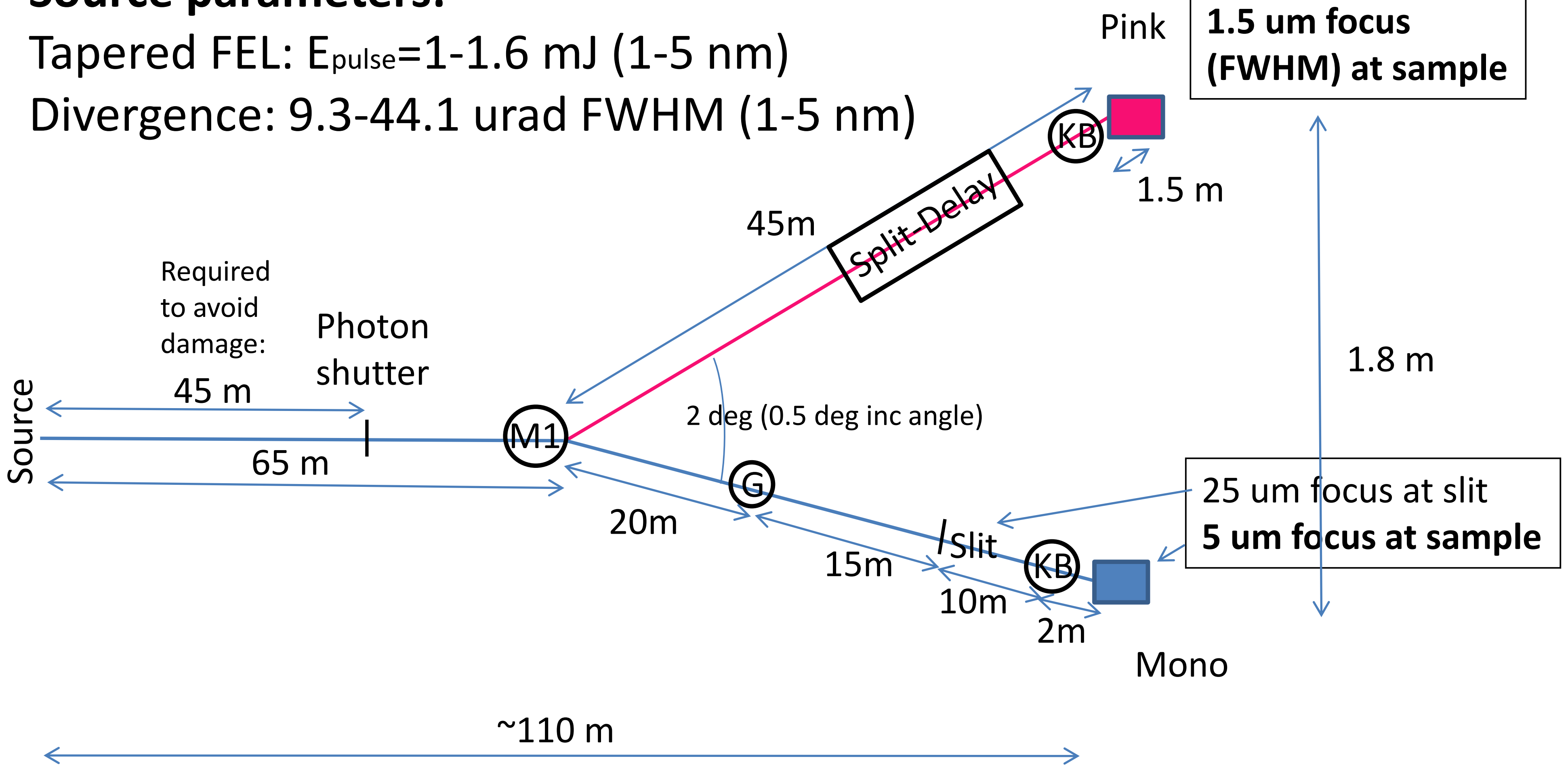
HERMES parameters	Vertical Focusing Mirror	Horizontal Focusing Mirror
Mirror length	300 mm	400 mm
Focal length	1200 mm	800 mm
Aperture stop	1.20 mm	1.48 mm
Incidence angle	4.0 mrad	3.7 mrad

Soft X-ray beamline for MAX IV

Source parameters:

Tapered FEL: E_{pulse}=1-1.6 mJ (1-5 nm)

Divergence: 9.3-44.1 urad FWHM (1-5 nm)



Design by Peter Salen

Beamline for CompactLight

- In view of the smaller beam energy, the CompactLight FEL would produce pulses with lower pulse energies.
- It is important to optimize photon transport and get as many coherent photons to the sample as possible.
- Maximize the transverse coherence of FEL emission.
- Maximize the emission into the fundamental (transverse) Gaussian mode (minimize M^2).
- Devise a strategy to keep the virtual source position in the undulator matched to the focus of the steering mirror.
- Consider performing mochochromatization in the undulator. The conventional monochromator has only a few percent efficiency.

Summary

- The beamline is an essential component of the FEL facility.
- The typical length is at least 100 meters. This needs to be taken into account when planning the facility.
- While designing the linac and undulator, we may want to think in terms of the mono and pink operation modes.
- The efficiency of the monochromator is < 2-5 %. Important to study options for performing monochromatization in the undulator.
- The CompactLight FEL cannot deliver high pulse energies. Hence, we need to consider nm-scale focusing.
- In Uppsala, we are building competence in designing FEL beamlines and can offer to investigate the options for the beamline design for CompactLight.

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Thank you!

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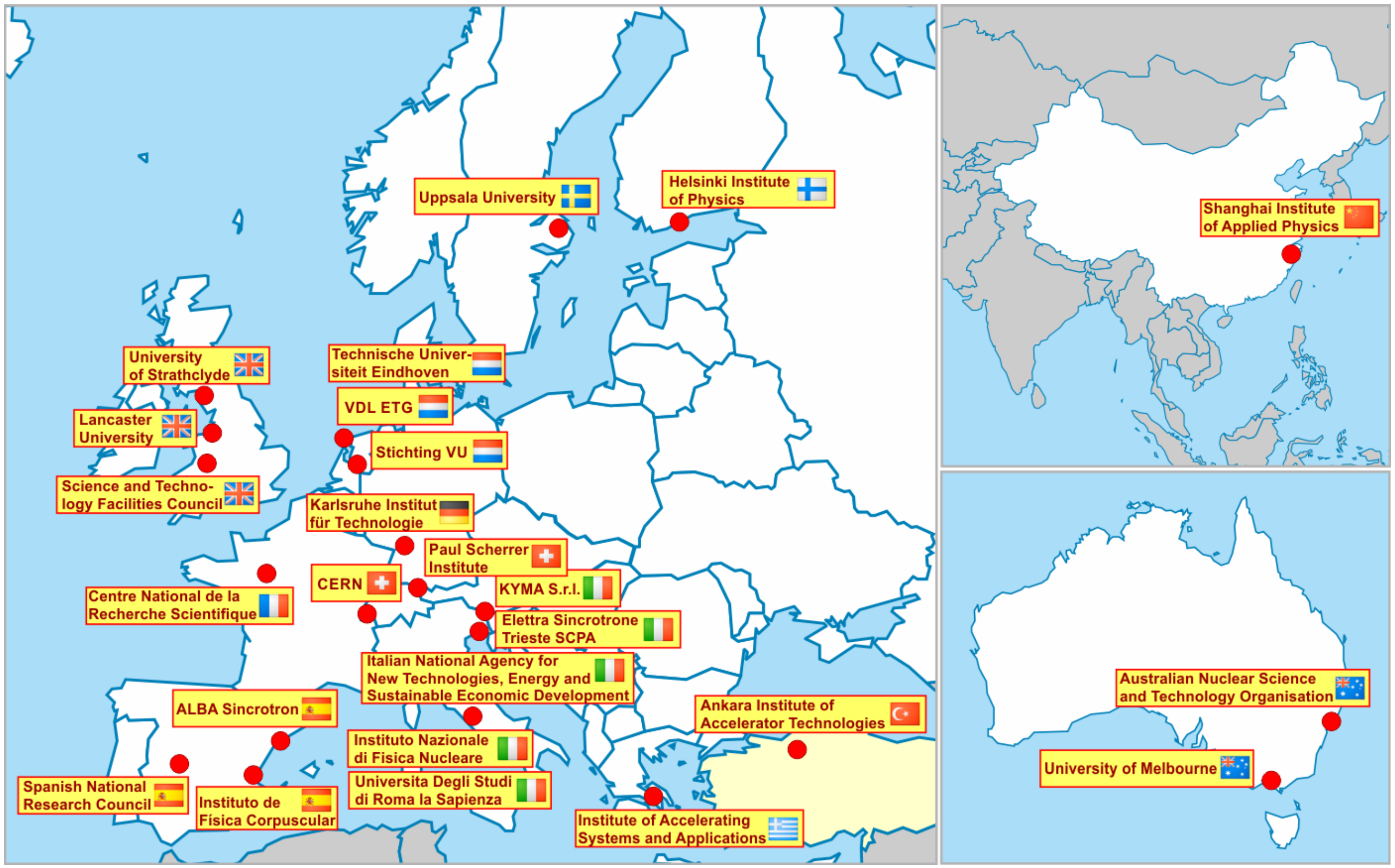

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