



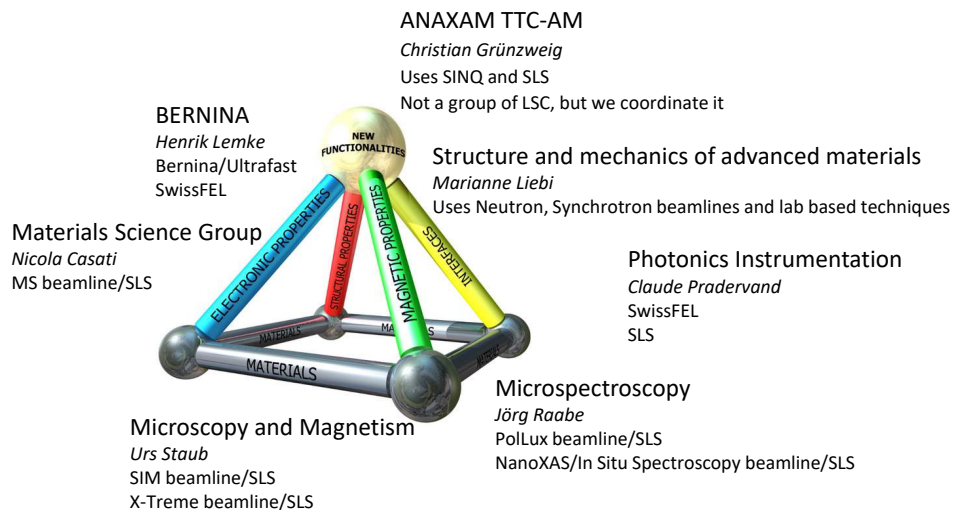
Frithjof Nolting :: Head of LSC :: Paul Scherrer Institute

## Laboratory for Condensed Matter LSC – beamlines at SLS 2.0

SLS 2.0 User Information Workshop 28.02.2022



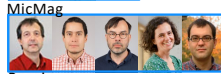
## The Laboratory for Condensed Matter - LSC



Research in condensed matter and materials science and providing a platform for high-impact research employing high-resolution X-ray spectroscopy, imaging and diffraction at SLS and SwissFEL

# People at LSC

## Staff scientist



## Postdocs



## PhD students



## Technicians/engineers



## Photonics/Photonen Instrumentation Group



## Other



# Technology Transfer Center ANAXAM

**a n a x a m**  
analytics with neutrons and x-rays for advanced manufacturing



**Our mission**  
We provide industry access to cutting-edge material analytics originally developed for basic research, but now made available to address industrial challenges.

**Our vision**  
Advanced analytics for the products and processes of tomorrow

**Imaging**

- 3D material distribution analysis
- Defect and porosity analysis in 3D
- Wall thickness analysis in 3D
- 3D residual stress comparison analysis
- Science Engineering

**Diffraction & Scattering**

- Atomic phases and structural characterization
- Residual stress analysis
- Long-range order characterization

**Spectroscopy**

- Chemical imaging analysis
- Chemical characterization

**Tailor-made Infrastructure**

- Sample preparation and pre-/post-characterization
- Clean rooms with process equipment



**“Working with ANAXAM, who created the tailor-made test bench, and in combination with neutron imaging, we were able to investigate non-destructively the micro-movements of the brake components.”**  
Audi Sport GmbH

**Main sponsors**

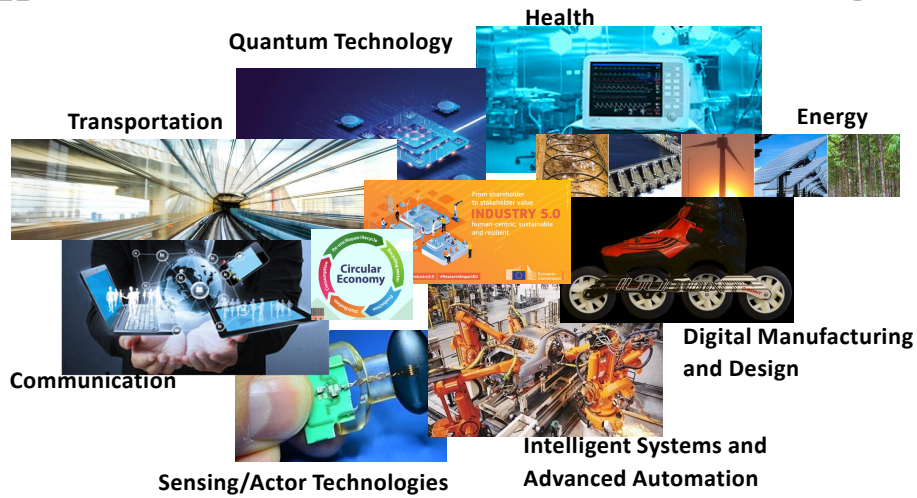
**Supporter**

**Members selection**

See also:  
SLS TT AG  
<https://www.synchrotron-analysis.ch/>

[www.anaxam.ch](http://www.anaxam.ch)

# Advanced materials for future technologies



- understanding the dynamics of phase transitions and non-equilibrium states covering the second down to the femtosecond time scales
- understanding inhomogeneous systems, heterostructures and devices from the microscale down to the nanometer

	2022	2023				2024				2025				2026			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Overall		SLS user operation				Dark period								SLS2 user operation with reduced number of beamlines			
Machine		Phase 0				Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning			
Beamlines group 1		Phase 0				installations, modifications and upgrades as 2nd priority				inst. modif. and upgr. 1st priority				commissioning			
Beamlines group 2		Phase 0				installations, modifications and upgrades as 3rd priority				inst. modif. and upgr. 2nd priority				installations, modifications and upgrades as 1st priority			
		SLS2 user operation				shutdown				commissioning				SLS2 User operation			
		ScSB & Bi-G2 Id installation				SB commissioning				user operation				user operation			
		modifications				commissioning				user operation				user operation			
		front end completion				commissioning											

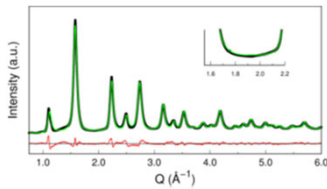
	Before	During dark period	1. block	shutdown	2. block	>2027
MS	Small modification	FE etc.	Pilot/Industry		Full operation	> New ID?
Pollux	Smaller modifications	FE etc.	Pilot		Full operation	> New bending?
ISS		FE and "move" to next bending	Pilot		Full operation	> New beamline?
X-Treme	New Endstation, new RMU		None	FE, New IDs, CMU, FMU	Pilot/Full operation	
SIM	Optic upgrade, new endstation	FE etc, New IDs	Pilot		Full operation	

## MS beamline – a hard X-ray diffraction

Nicola Casati, Antonio Cervellino, Shih-Wen Huang, Michael Lange, Dominik Meister  
Structural characterization of materials

### All flavours of scattering

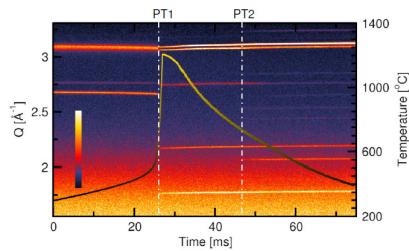
- Powder
- Single crystal
- Total scattering
- Surface
- Anomalous
- Small angle
- Diffuse



Evolving methodology

### Key experimental topics

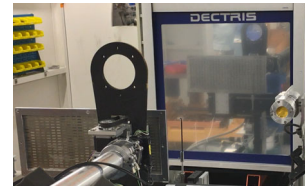
- Time resolved
- High-quality
- High-throughput
- *In situ/operando*
- On-edge



Building new setups

### Scientific areas of interest

- Condensed matter Physics
- Materials
- Chemistry
- Pharmacy
- Energy
- Metallurgy
- Geology



Expanding industrial applications

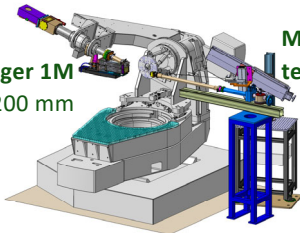
## ADvanced DiffrAction for Materials Science (ADDAMS) a diffraction beamline

Structural characterization of materials: Crystals, powder, surface, amorphous  
High quality, *in situ, operando*, anomalous, time resolved, high throughput

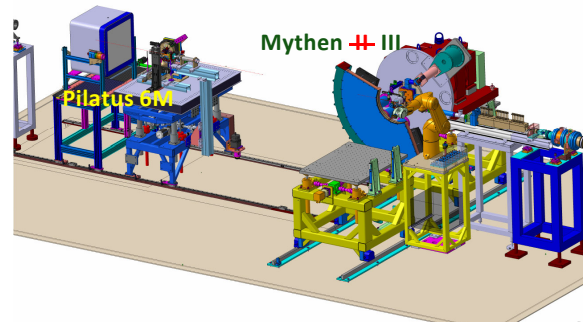
2 stations, 3 experimental tables for 1D, 2D and 3D geometries  
Ease of operation is very important as setups change frequently

Eiger 500K @ 1204 mm

22kHz Eiger 1M  
@ 50-200 mm

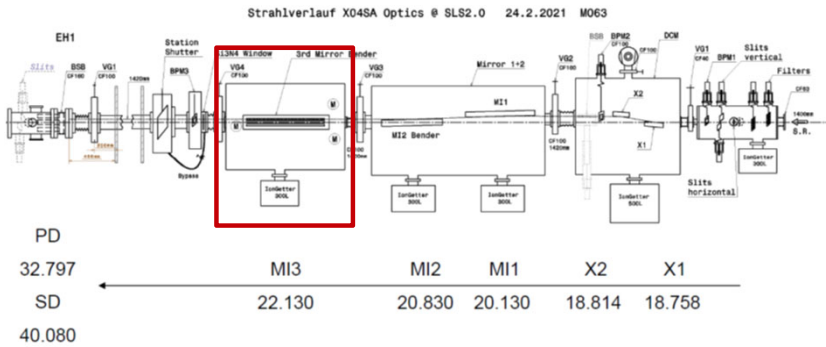
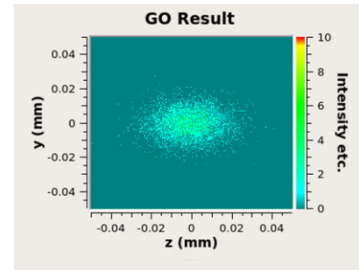


Mo source for testing



## ADDAMS upgrade for SLS 2.0

- Insertion of a new horizontal mirror instead of sagittal mono bender  
this leads to improved achromatic focussing, better operability
- Mythen III detector for measurements across elemental edges
- Refurbishment of components

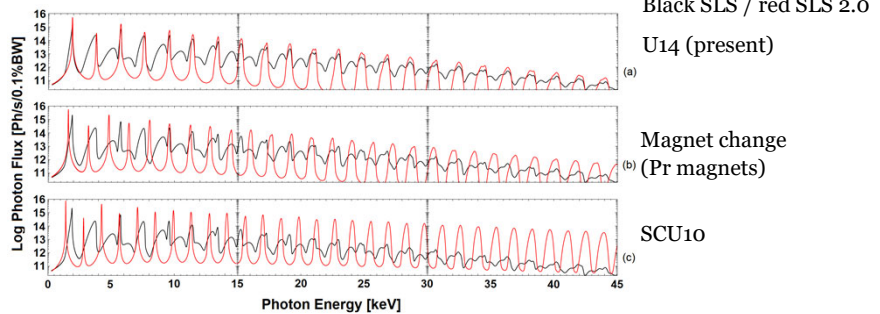


Calculated focal spot  
 @PD 41 x 26  $\mu\text{m}$  FWHM  
 (previous exp 80 x 30  $\mu\text{m}$ )  
 @SD 24 x 16  $\mu\text{m}$  FWHM  
 (previous exp 130 x 40  $\mu\text{m}$ )

## ADDAMS upgrade plan and future

- Mythen III installation completed in 2021
- Hor Mirror installation Design and procurement complete, installation planned for Autumn 2022
- SD station refurbishment Ongoing, to be completed in 2022 (includes new hexapod, Mo source and new Eiger units)
- Front End Design almost complete, planned for Darktime


Beyond 2024, we plan for an upgrade of the undulator, either entire or limited to magnets



2022	2023				2024				2025				2026																							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4																				
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D												
Overall	SLS user operation				Dark period								SLS2 user operation with reduced number of beamlines				shutdown				commissioning				SLS2 User operation											
Machine	Phase 0				Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning				user operation				ScSB & Bi-Gr2 Id installation				SB commissioning				user operation							
Beamlines group 1	Phase 0				installations, modifications and upgrades as 2nd priority								inst. modif. and upgr. 1st priority				commissioning				user operation				modifications				commissioning				user operation			
Beamlines group 2	Phase 0				installations, modifications and upgrades as 3rd priority								inst. modif. and upgr. 2nd priority				installations, modifications and upgrades as 1st priority				front end completion				commissioning				user operation							

	Before	During dark period	1. block	shutdown	2. block	>2027
MS	Small modification	FE etc.	Pilot/Industry		Full operation	> New ID?
PolLux	Smaller modifications	FE etc.	Pilot		Full operation	> New bending?
ISS		FE and "move" to next bending	Pilot		Full operation	> New beamline?
X-Treme	New Endstation, new RMU		None	FE, New IDs, CMU, FMU	Pilot/Full operation	
SIM	Optic upgrade, new endstation	FE etc, New IDs	Pilot		Full operation	



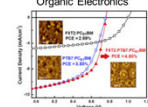
PAUL SCHERRER INSTITUT

# PolLux beamline (soft X-rays)

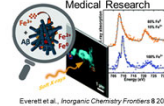
PolLux - X07DA: Scanning Transmission X-Ray Microspectroscopy  
 Jörg Raabe, Ben Watts, Simone Finizio, Blagoj Serafimov, close collaboration with Rainer Fink from Friedrich-Alexander-Universität

### Composition & Chemistry of Materials

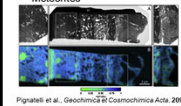
- Higher flux:
  - Faster measurements
  - Improved focus
  - Improvements in image quality may depend on radiation damage
- Mono upgrade:
  - More elements, e.g. S, P & Cl



Farinas et al., Organic Electronics 41, 2017, 130-136



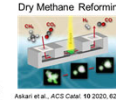
Everett et al., Inorganic Chemistry Frontiers 9, 2021, 1439



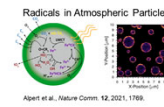
Fignatelli et al., Geochimica et Cosmochimica Acta 209, 2017, 106

### Catalysis and Environmental cells

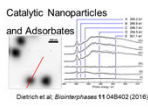
- New gas cabinets
- Easier use of reactive gasses
- Higher flux:
  - Faster measurements
  - Improved focus
- Mono upgrade:
  - More elements, e.g. S, P & Cl



Asahi et al., ACS Catal. 10, 2020, 8223



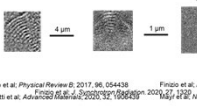
Apet et al., Nature Comm. 12, 2021, 1769



Dietrich et al., Biointerphases 11, 04B402 (2016)

### Magnetisation Dynamics

- Demand for investigation of higher frequency processes (e.g. in SAFs and AFMs)
  - SLS 2.0 will not offer low- $\alpha$  optics, limit to 70 ps FWHM pulses
- New detection protocol for time-resolved imaging
  - Time-of-arrival of X-ray photon is measured
  - Operates independently from SIS master clock, allowing excitation with arbitrary frequencies
  - Demonstrated time resolution of 30 ps, independent of filling pattern

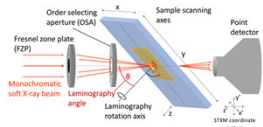


Finizio et al., Physical Review B 2017, 96, 054438

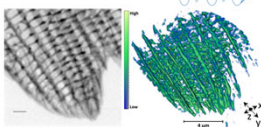
Aliev et al., ACS Photonics 2020, 7, 1222-1230

### 3D Imaging via Laminography

- Record projections while rotating sample
- Tomography: sample rotation axis perpendicular to beam
- Laminography: sample rotation axis tilted to beam
- Allows extended samples supported on a flat membrane.
- Resolution down to ca. 30 nm
- Higher flux from SLS 2.0 will decrease measurement time



Witte et al., Nano Letters 2020, 20(2): 1306-1314

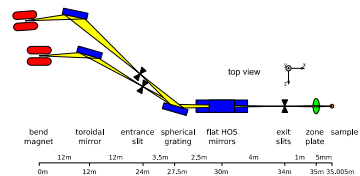
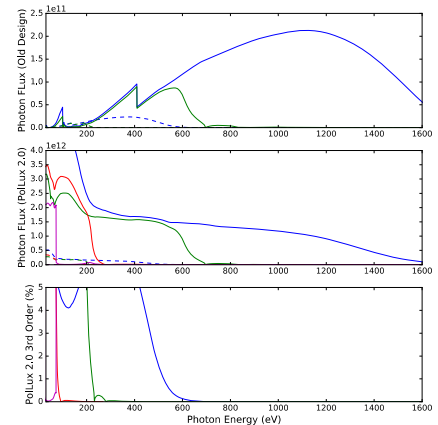
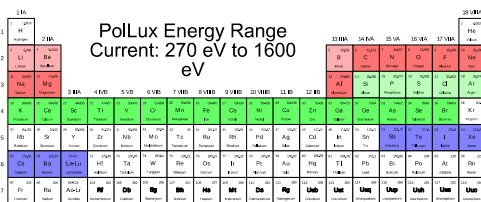


## PolLux SLS 2.0 Upgrade

- Minor adaption to new source position during phase-1:
  - Remain in operation as much as possible.
  - Return to normal operation after 1<sup>st</sup> long shutdown.
- New ring gets **40x** more flux through the acceptance angle of the beamline.
- New detector timing electronics gives temporal resolution of **30 ps independent of ring mode**.
- Complementary high-performance STXM available at SIM (undulator beamline).
- Upgrade monochromator in 2027:
  - Extend energy range – covering Li to Br ( $3 \leq Z \leq 35$ )
  - Improve spectral purity (remove higher orders)
  - Improve efficiency (higher flux)


## Monochromator Upgrade (2027)

- Use adjacent bend magnet for second beam path optimized for low energies.
- Extend energy range down to ~50 eV and improve spectral purity.
- Access to all light elements: (except H, He)
  - **K-edges** from Li to Al
  - **L-edges** from Al to Br
- Installation of extra components can be done in normal shutdown periods and so won't interrupt normal operations.



2022	2023				2024				2025				2026															
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D				
Overall	SLS user operation				Dark period								SLS2 user operation with reduced number of beamlines															
Machine	2021-2023 Phase 0				Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning															
Beamlines group 1					installations, modifications and upgrades as 2nd priority				inst. modif. and upgr. 1st priority				commissioning				user operation											
Beamlines group 2					installations, modifications and upgrades as 3rd priority				inst. modif. and upgr. 2nd priority				installations, modifications and upgrades as 1st priority				front end completion											
	Before				During dark period								1. block				shutdown				2. block				>2027			
MS	Small modification				FE etc.								Pilot/Industry								Full operation				> New ID?			
Pollux	Smaller modifications				FE etc.								Pilot								Full operation				> New bending?			
ISS					FE and "move" to next bending								Pilot								Full operation				> New beamline?			
X-Treme	New Endstation, new RMU												None				FE, New IDs, CMU, FMU				Pilot/Full operation							
SIM	Optic upgrade, new endstation				FE etc, New IDs								Pilot								Full operation							

Page 15

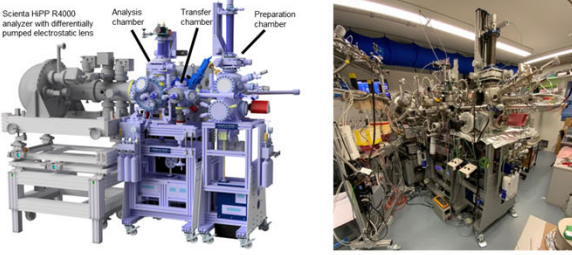


PAUL SCHERRER INSTITUT

## In Situ Spectroscopy beamline (soft X-rays)

X07DB: Soft X-Ray Ambient Pressure Photoelectron Spectroscopy (former NanoXAS)  
 Luca Artiglia (ENE/PSI), Zbynek Novotny (PSD and UniZH), Jörg Raabe (PSD)  
 Close collaboration with Jeroen van Bokhoven (ENE/PSI), Markus Ammann (ENE/PSI) and Jürg Osterwalder (UniZH)

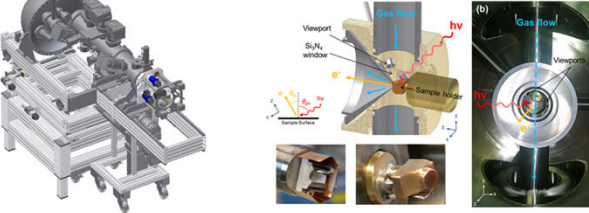
### Endstation: Solid-Liquid Interface Chamber



Z. Novotny et al., Rev. Sci. Instrum. 91, 023103 (2020).

- Backfilling configuration
- Solid-liquid (PHOENIX I beamline) and solid-gas interface (In Situ Spectroscopy beamline)
  - UHV sample preparation
- Main research topics: **corrosion science, heterogenous catalysis, surface science.**

### Endstation: Solid-Gas Interface Chamber



- Flow tube configuration
- Small volume (ca. 100 cc)
- Possibility to **move samples, heat (>1200 K) or cool down (<200 K)**
- Fast dosing of **sticky gases, transient photoemission experiments**
- Main research topics: **surface/environmental chemistry and catalysis**

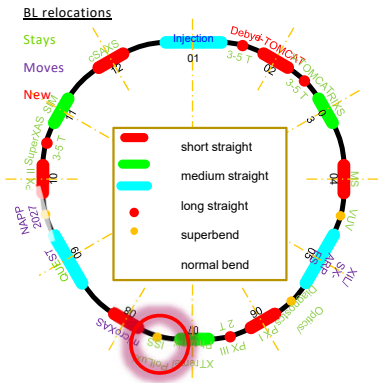
Page 16



# In Situ Spectroscopy beamline at SLS 2.0

## Phase II

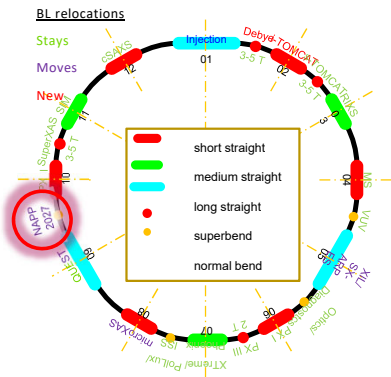
- Stay, but own bending magnet, e.g. fully decoupled from PoLLux



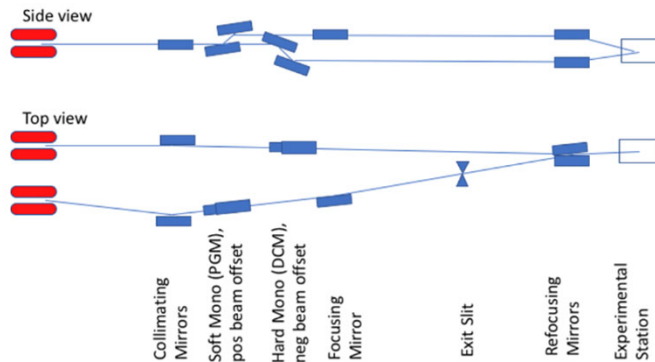
# New In Situ Spectroscopy beamline at SLS 2.0

## Long-term: Phase III

- Optics concept of the planned beamline at X09D (internally called “NAPP 2027”)
- Energy range:
  - PGM: 250 – 2000 eV, DCM: up to 6 keV (APXPS, NEXAFS, HAXPES)
  - If funding secured, beamline open for users after 2027



**Beamline layout**



2022	2023				2024				2025				2026											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4								
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Overall	SLS user operation				Dark period								SLS2 user operation with reduced number of beamlines											
Machine	Phase 0				Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning											
Beamlines group 1	Phase 0				installations, modifications and upgrades as 2nd priority				inst. modif. and upgr. 1st priority				commissioning											
Beamlines group 2	Phase 0				installations, modifications and upgrades as 3rd priority				inst. modif. and upgr. 2nd priority				installations, modifications and upgrades as 1st priority											
	SLS2 user operation				shutdown				commissioning				SLS2 User operation											
	Sc:SB & Bi-G2 Id installation				SB commissioning				user operation				user operation											
	modifications				commissioning				front end completion				commissioning											
	user operation				user operation				user operation				user operation											

	Before	During dark period	1. block	shutdown	2. block	>2027
MS	Small modification	FE etc.	Pilot/Industry		Full operation	> New ID?
Pollux	Smaller modifications	FE etc.	Pilot		Full operation	> New bending?
ISS		FE and "move" to next bending	Pilot		Full operation	> New beamline?
X-Treme	New Endstation, new RMU		None	FE, New IDs, CMU, FMU	Pilot/Full operation	
SIM	Optic upgrade, new endstation	FE etc, New IDs	Pilot		Full operation	

Page 19

## X-Treme beamline (soft X-rays)

X-Treme / X07MA: X-ray absorption spectroscopy at high magnetic field and low temperature

Cinthia Piamonteze, Jan Dreiser, Stefan Zeugin, Stefano Rusponi (EPFL), Harald Brune (EPFL)

### Single-Ion Molecular Magnets on Surfaces

- Potential for molecular storage and (quantum) information processing devices
- LnPc<sub>2</sub> molecules deposited on Ag(100) single crystals and with an interlayer of magnesium oxide (MgO)
- MgO: dramatic enhancement of the magnetic hysteresis for both TbPc<sub>2</sub> and DyPc<sub>2</sub>
- Current world record of remanence and hysteresis opening of any molecular magnet on a surface

C. Wäckerlin, F. Donati, A. Singha, R. Baltic, S. Rusponi, K. Diller, F. Patthey, M. Pivetta, Y. Lan, S. Kiyatskaya, M. Ruben, H. Brune, and J. Dreiser, Adv. Mater. **28**, 5195 (2016).

### Hindering magnetic dead layer of manganites by heterostructures

- Ferromagnetism of 1 unit cell thick La<sub>0.7</sub>Ba<sub>0.7</sub>MnO<sub>3</sub> ferromagnetic up to 130K when interfaced with SrRuO<sub>3</sub>
- Investigate magnetism of La<sub>0.7</sub>Ba<sub>0.7</sub>MnO<sub>3</sub> and SrRuO<sub>3</sub> separately

Piamonteze, C. et al. Applied Physics Letters **118**, 152408 (2021).

Page 20

	Current	SLS 2.0
# Periods	32	75
Length	1.8m	3.4m
Polarization	0°-90° linear	0°-180° linear
	circular left/right	circular left/right
1 <sup>st</sup> harmonic Max. Energy	950eV (up to Cu L <sub>2,3</sub> )	1400eV (up to Dy M <sub>4,5</sub> )
Left/right polarization switch time	~ 30 seconds	~ 2-5 seconds

- Fast polarization switching
  - improved signal/noise for magnetization curves
- 180° Linear polarization control
  - versatile x-ray linear dichroism measurements
- Increased first harmonic energy range up to Dy M<sub>4,5</sub> edges
  - in the first harmonic the full circular polarization is available without flux loss. In higher harmonics high circular polarization is available at a cost of flux

## Beamline Optics – new beam spot sizes

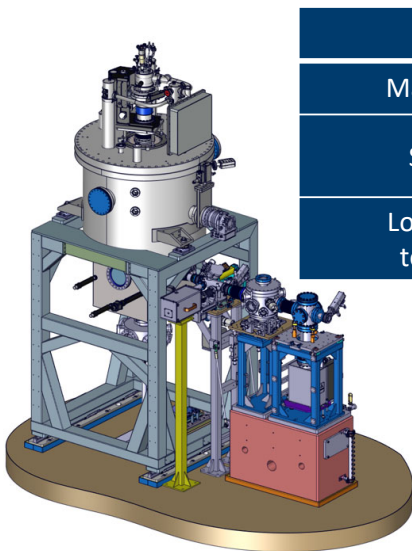
(\*)FWHM at 700eV, cff=5, exit slit = 30 $\mu$ m

Spot size (*) in $\mu$ m (Hor. x Ver.)	Current	SLS 2.0
Defocused	Not available	3400 x 3700
Diverging	500 x 1230	630 x 2100
Focused	186 x 30	17 x 11.5

- Refocusing mirror with three surfaces giving three sizes of beam spot
- Smaller focused spot size:
  - possibility to measure small crystals, lithographically prepared samples
- Larger defocused spot size:
  - further decrease radiation damage and surface charging when needed
- Intermediate spot size:
  - Intermediate size samples which still benefit from a larger beam spot can still be measured

Page 23

## End-station



SNF R'Equip proposal from Stefano Rusponi granted. Matching funds from EPFL

	Current	SLS 2.0
Maximum field	7.0 T	14.0 T
Sweep rate	2.0 T/min	5 T/min (up to 10T) 1 T/min (10-14T)
Lowest sample temperature	2.0K	2.0K

- Higher fields:
  - saturation at higher temperatures for paramagnetic samples
  - phase transitions under high magnetic fields
- Faster sweep rate:
  - more efficient use of beamtime
  - measurement of faster relaxation processes
- Delivery foreseen before SLS dark time


Page 24

	2022	2023				2024				2025				2026															
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4												
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D				
Overall		SLS user operation				Dark period								SLS2 user operation with reduced number of beamlines				shutdown	commissioning	SLS2 User operation									
Machine	2021-2023 Phase 0					Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning				user operation				Sc:SB & Bi-G2 Id installation	SB commissioning	user operation					
Beamlines group 1						installations, modifications and upgrades as 2nd priority								inst. modif. and upgr. 1st priority		commissioning		user operation				modifications		commissioning		user operation			
Beamlines group 2						installations, modifications and upgrades as 3rd priority								inst. modif. and upgr. 2nd priority		installations, modifications and upgrades as 1st priority				front end completion		commissioning							

	Before	During dark period	1. block	shutdown	2. block	>2027
MS	Small modification	FE etc.	Pilot/Industry		Full operation	> New ID?
Pollux	Smaller modifications	FE etc.	Pilot		Full operation	> New bending?
ISS		FE and "move" to next bending	Pilot		Full operation	> New beamline?
X-Treme	New Endstation, new RMU		None	FE, New IDs, CMU, FMU	Pilot/Full operation	
SIM	Optic upgrade, new endstation	FE etc, New IDs	Pilot		Full operation	

Page 25

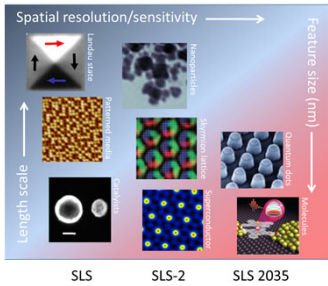


PAUL SCHERRER INSTITUT

## SIM beamline (soft X-rays)

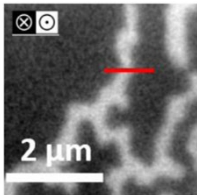
Surfaces / Interfaces: Microscopy (SIM) Beamline  
Armin Kleibert, Carlos Vaz, Pascal Schifferle

- New ptychography spectromicroscope to enable materials and device characterisation at nanoscale
- Nanometer surface sensitivity provided by XPEEM
- Open port to further new technical and scientific developments



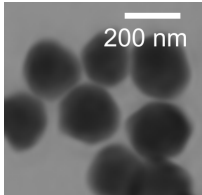
SLS    SLS-2    SLS 2035

### XPEEM



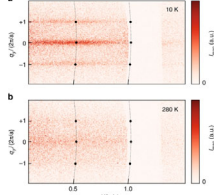
K. Zeissler *et al.*, Nat. Nanotechnol. (2018)

### Ptychography



Au nanoparticles  
Resolution: 7.5 nm

### RESOXS



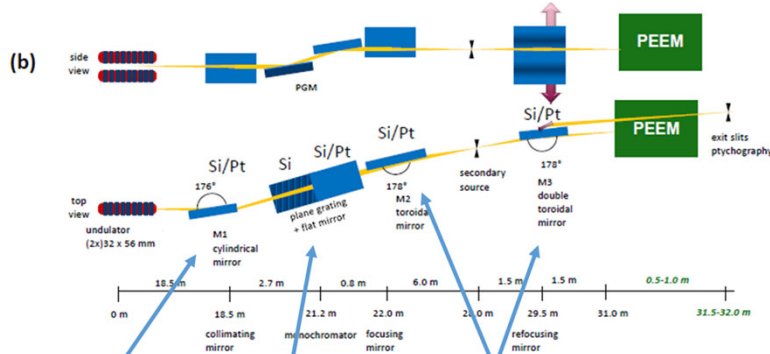
N. Leo *et al.*, Nat. Comm. (2018)

Page 26

## SIM optics Upgrade: 1<sup>st</sup> step, March, 2022

- Installation of toroidal mirrors in new position (with two selectable focal points)
- Shifting of the XPEEM microscope to new position
- Installation of new exit slits for ptychography microscope

SLS2:



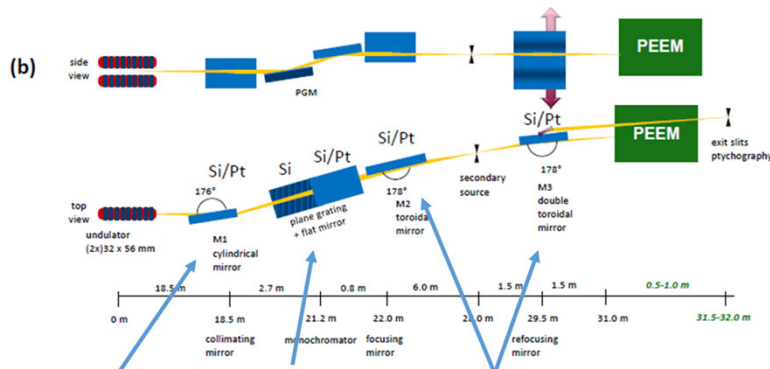
- Improved cooling
- Improved cooling & blazed gratings
- Improved optics / ptychography
- XPEEM electronics upgrade
- EIGERII detector XPEEM

## SIM optics Upgrade: 2<sup>nd</sup> step, October, 2023

- Improved (active) cooling of the optics
- New focusing mirrors and PGM
- Cleaning of all optical elements

2024  
New IDs and  
Phasematcher

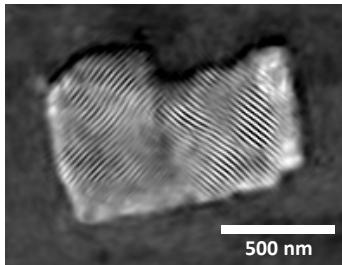
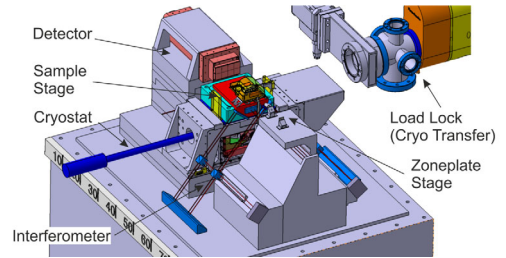
SLS2:



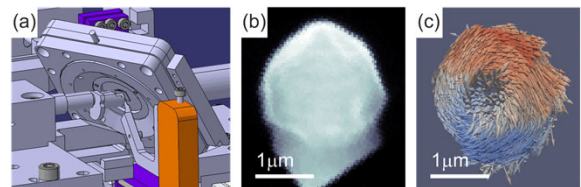
- Improved cooling
- Improved cooling & blazed gratings
- Improved optics / ptychography
- XPEEM electronics upgrade
- EIGERII detector XPEEM

# Commissioning of Ptychography endstation

- Spectromicroscopy with spatial resolution < 10 nm
- Sample temperature down to 10 K
- User-friendly operation
- Later upgrade with magnetic fields



Spin spirals in BiFeO<sub>3</sub> particles



Laminography mode for 3D (magnetic) imaging

In collaboration with SNI, Basel

# Wir schaffen Wissen – heute für morgen

SLS 2.0 to explore the nanoscale in devices and complex systems - Thanks to all LSC staff and all of PSI

	2022				2023				2024				2025				2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Overall	SLS user operation				Dark period				SLS2 user operation with reduced number of beamlines				shutdown				SLS2 User operation			
Machine	Phase 0 2021-2023				Dismantling SLS				Installation new ring				Beam commissioning and vacuum conditioning				SLS2 installation			
Beamlines group 1					installations, modifications and upgrades as 2nd priority				inst. modif. and upgr. 1st priority				commissioning				user operation			
Beamlines group 2					installations, modifications and upgrades as 3rd priority				inst. modif. and upgr. 2nd priority				installations, modifications and upgrades as 1st priority				front end completion			

	Before	During dark period	1. block	shutdown	2. block	>2027
MS	Small modification	FE etc.	Pilot/Industry		Full operation	> New ID?
PolLux	Smaller modifications	FE etc.	Pilot		Full operation	> New bending?
ISS		FE and "move" to next bending	Pilot		Full operation	> New beamline?
X-Treme	New Endstation, new RMU		None	FE, New IDs, CMU, FMU	Pilot/Full operation	
SIM	Optic upgrade, new endstation	FE etc, New IDs	Pilot		Full operation	

