METALBEAMS WORKSHOP 2024

MAX IV Research and Update

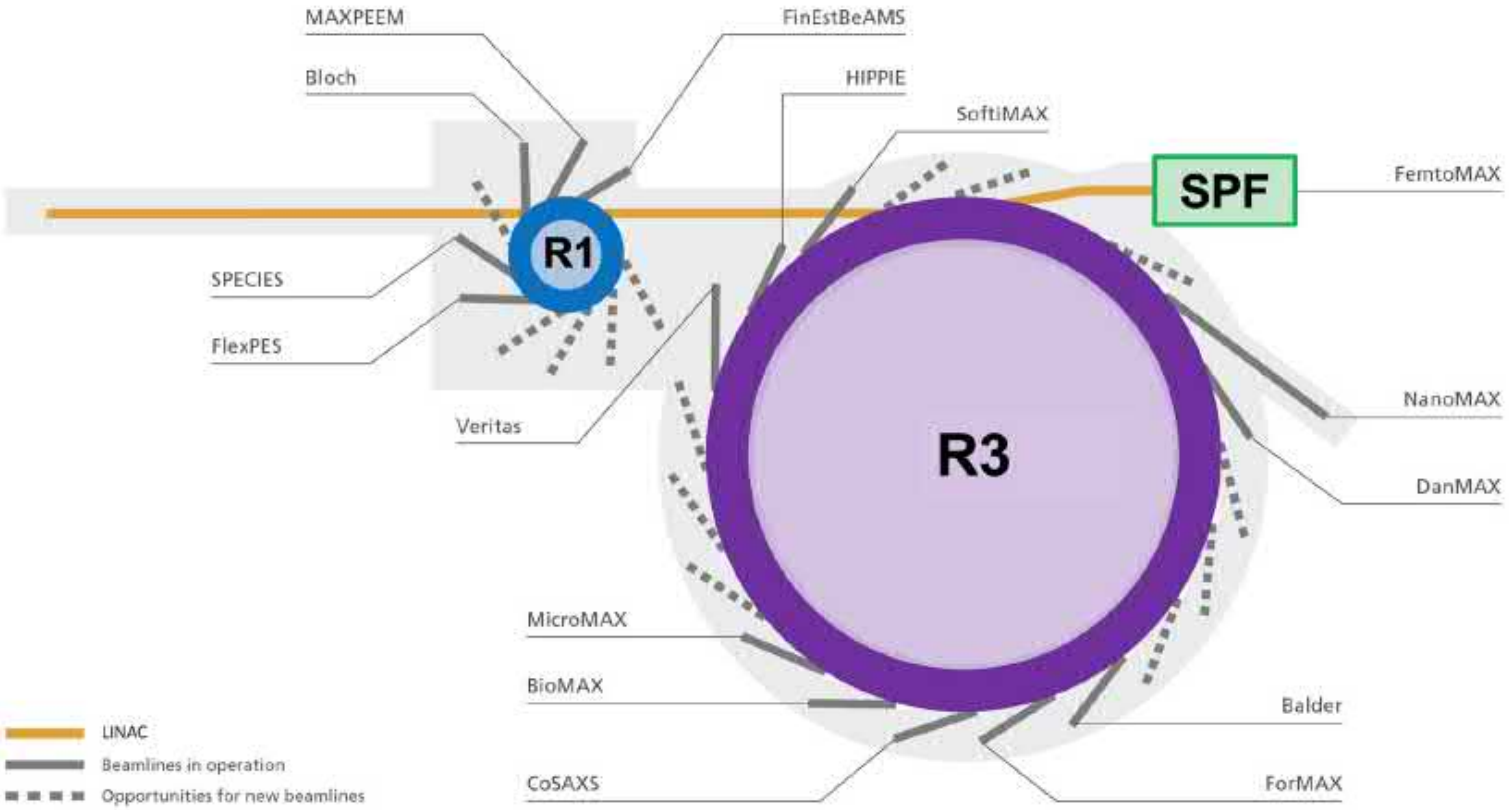
Joachim Schnadt, Science Director (interim)

Welcome to the world's first fourth-generation synchrotron light source!

www.maxiv.lu.se

Three accelerators to produce x-ray radiation of highest quality

Linac – Linear Accelerator
R1 - 1.5 GeV storage ring
R3 – 3 GeV storage ring



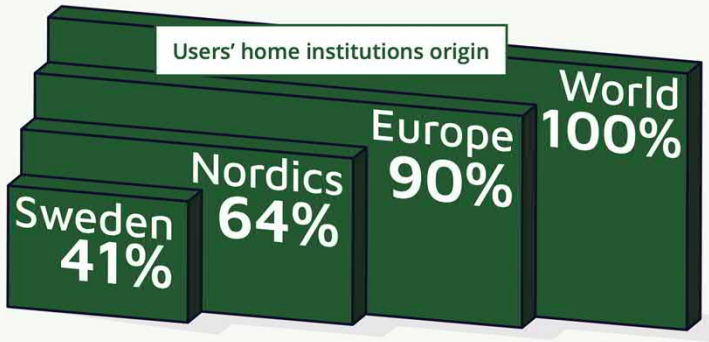
A. Robert *et al.*, "MAX IV Laboratory", Eur. Phys. J. Plus 138, 495 (2023)

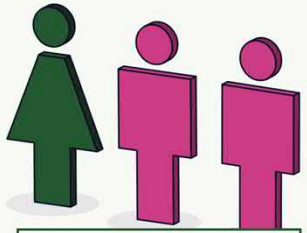
MAX IV is a user facility

2023 numbers

USERS

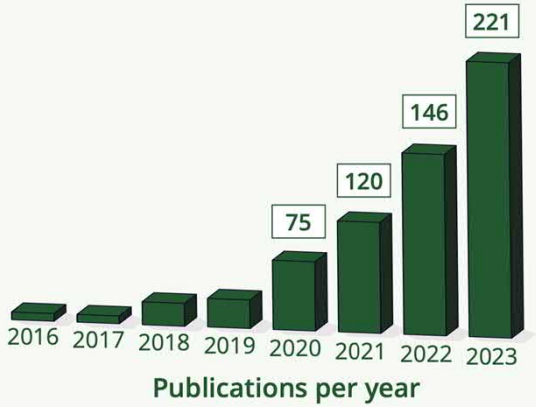
1732 unique users from **280** institutions across **34** countries out of which **14.7%** remote users

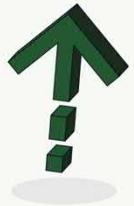




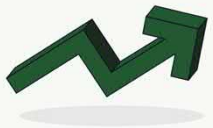
1 in 3 users is a female scientist

PUBLICATIONS





+51% increase of publications compared to 2022



651 publications 2016–2023

INDUSTRY

23 proprietary user groups including mediators

52% proprietary industry users from Sweden

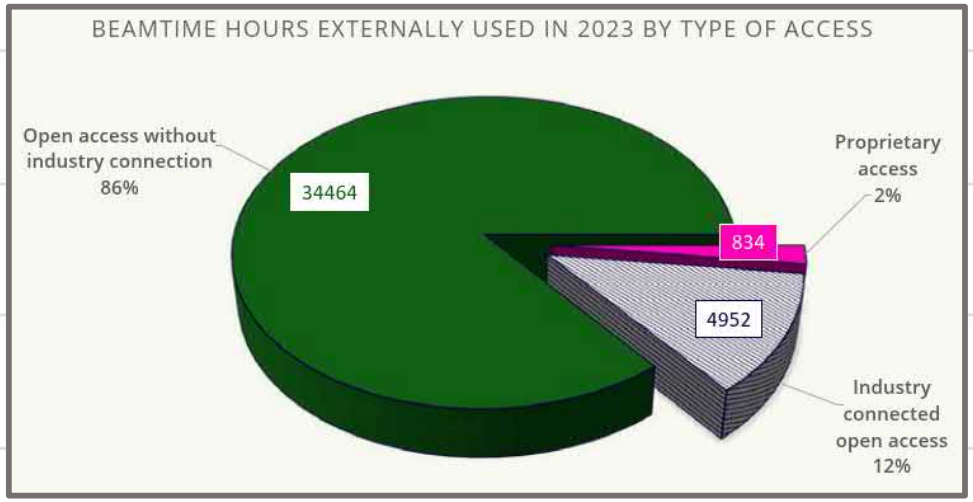
~4950 hours of beamtime for user scientific projects connected with industry

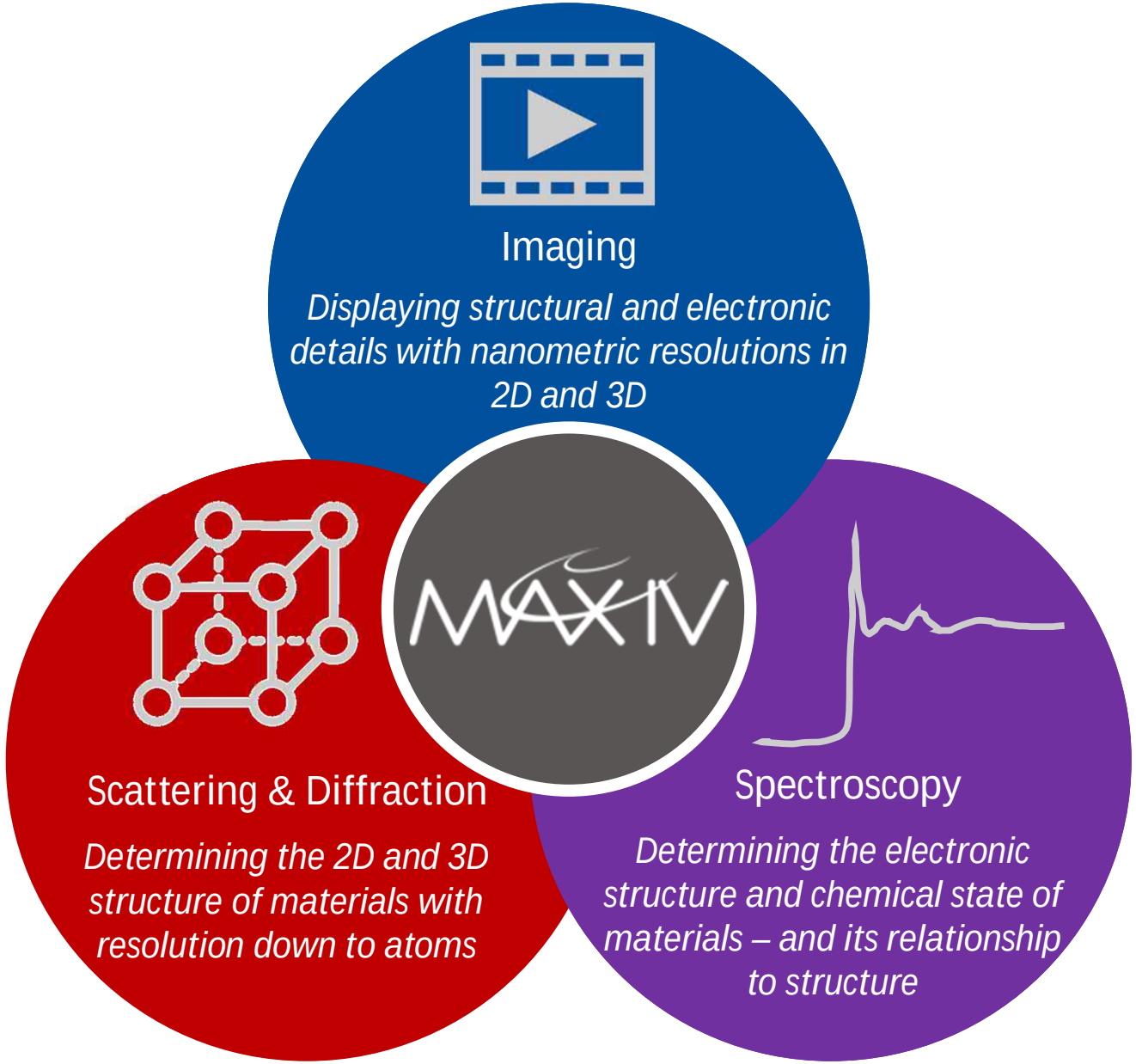
~850 hours paid proprietary beamtime

EMPLOYEES

294 full-time equivalents

INDUSTRY-CONNECTED BEAMTIME HOURS IN 2023 BY TYPE OF ACCESS AND INDUSTRY SECTOR

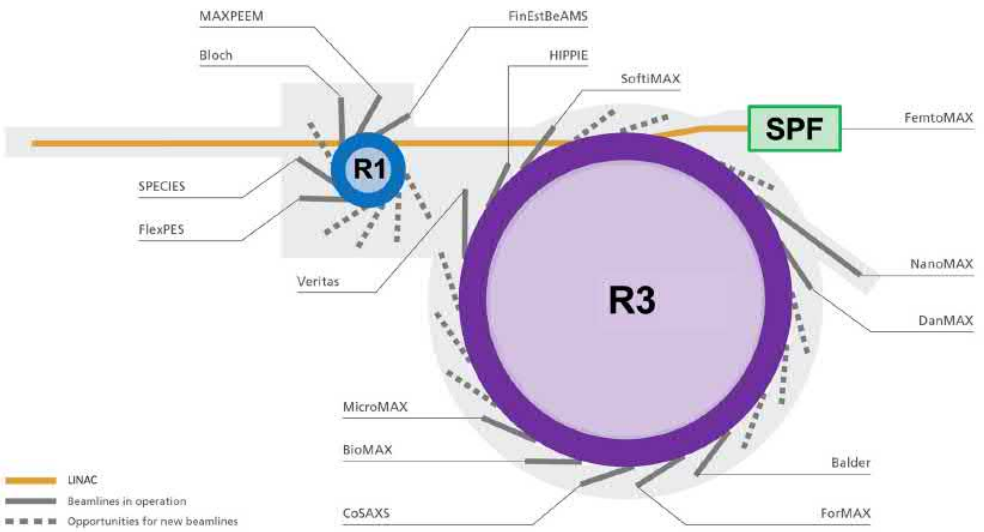




We illuminate with x-rays
– and we measure x-rays or electrons

Science at MAX IV

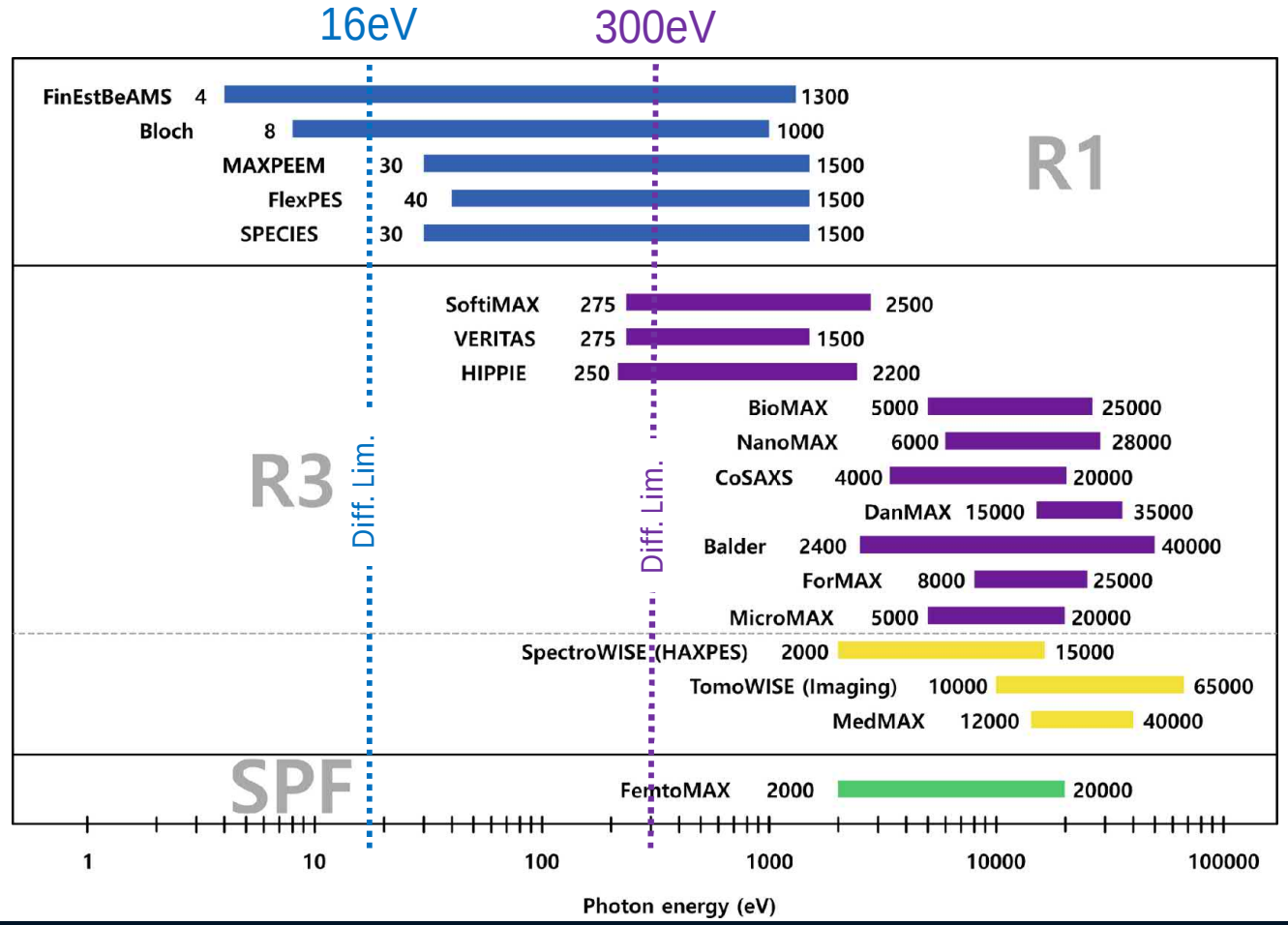
Beamlines



16 beamlines in operation

covering a broad X-ray energy range from 4 eV to 40 keV

3 beamlines in TDR phase



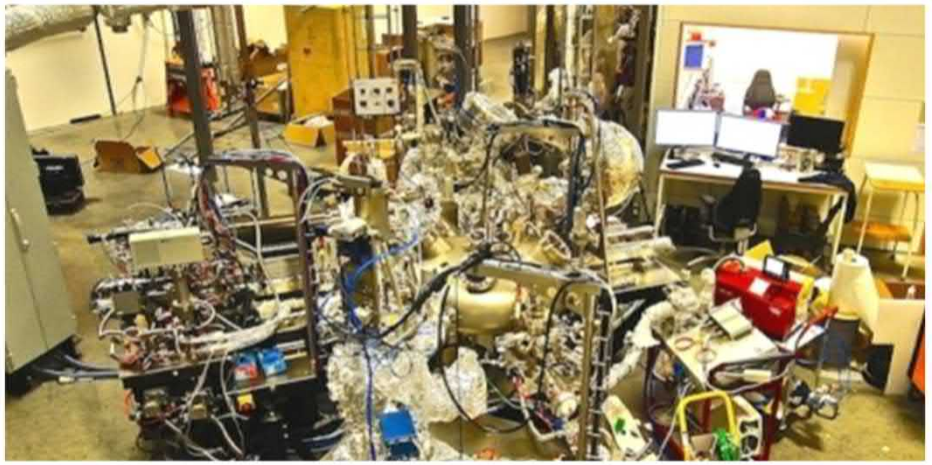
Soft X-rays

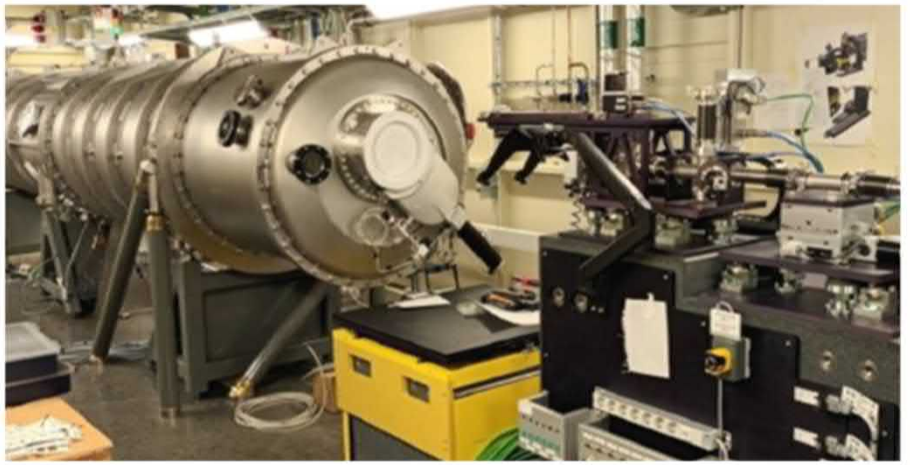
~ surface and sub-surface information

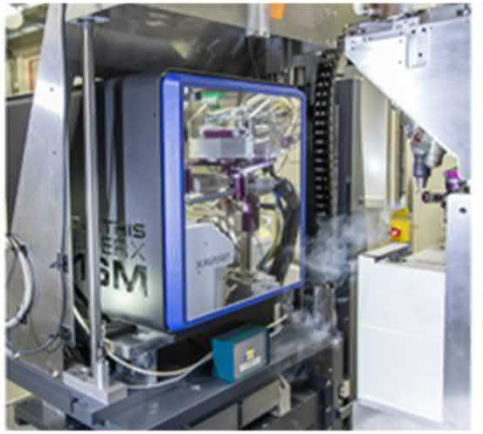
Hard X-rays

~ bulk information and buried interfaces

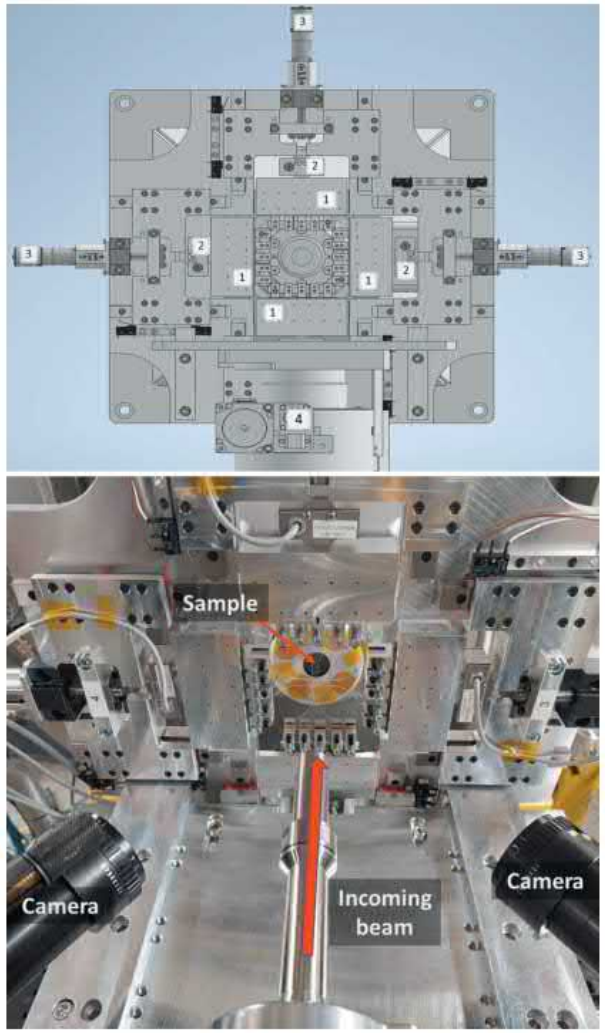
Some science examples – scattering and others

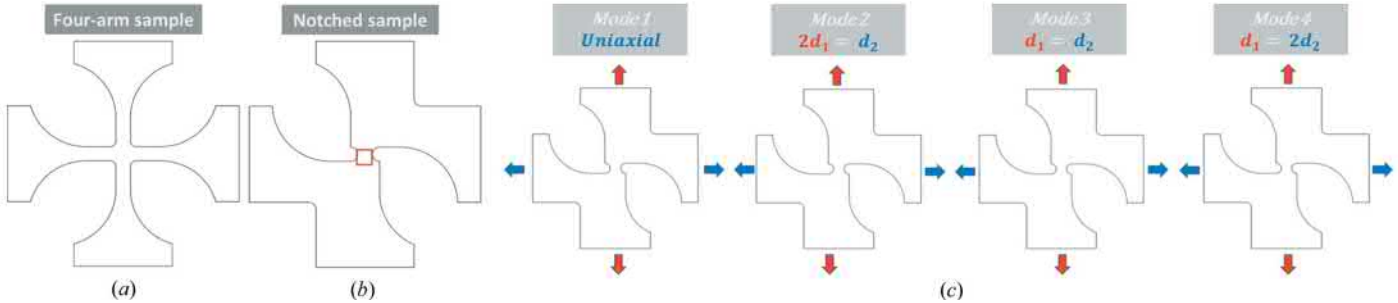






In situ characterisation of the mechanical reponse of materials by simultaneous SAXS/WAXS and digital image correlation (DIC) @ CoSAXS





Sample: 1 mm thick polycarbonate

P. Mota-Santiago et al., J. Appl. Cryst. 56 (2023) 967

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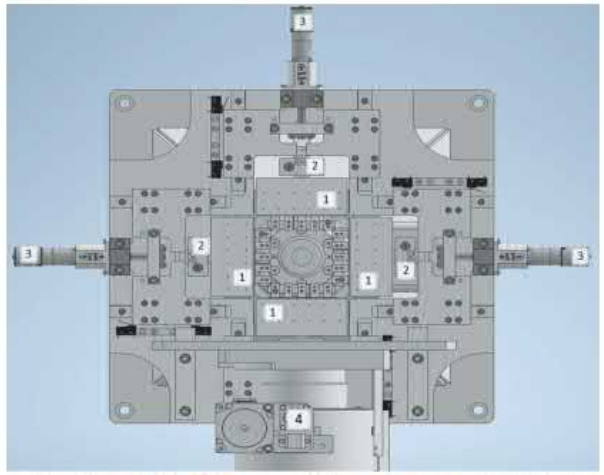
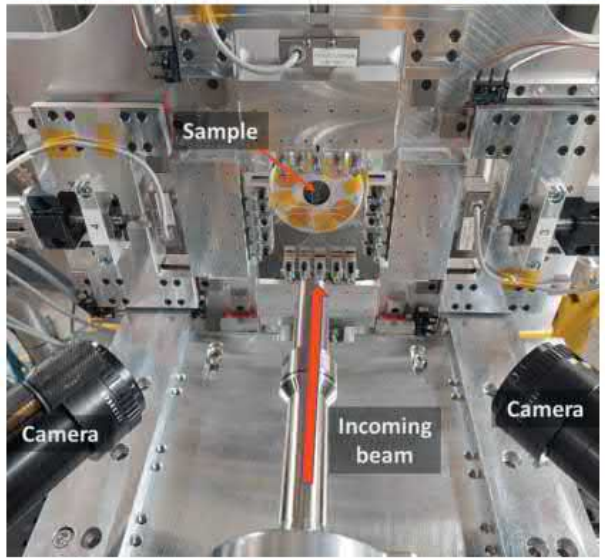
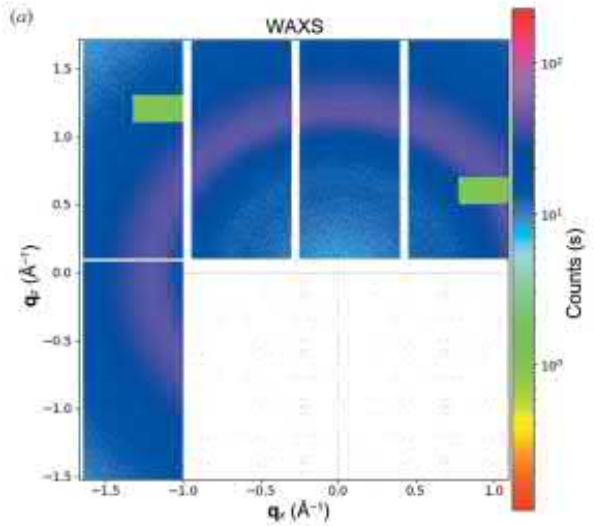
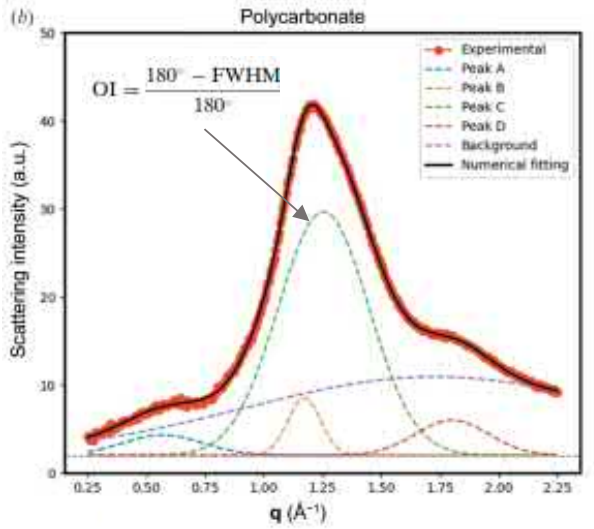


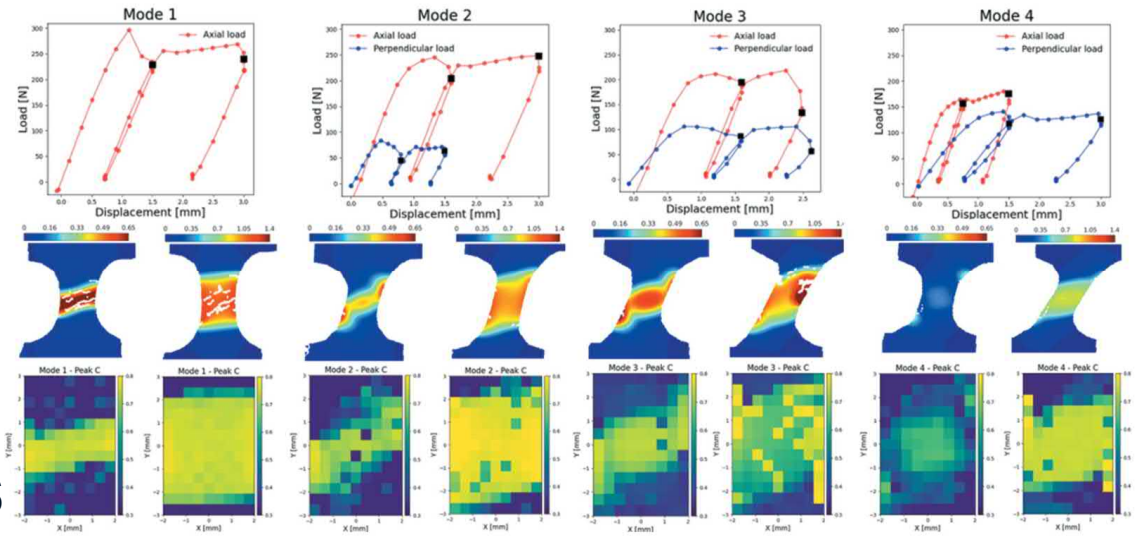






DIC

OI from WAXS



DIC: shows local deformation
(not the stronger deformation at the material boundaries; point towards high-straing zones at edges)
WAXS: shows degree of orientation of the PC fibers

P. Mota-Santiago et al., J. Appl. Cryst. 56 (2023) 967

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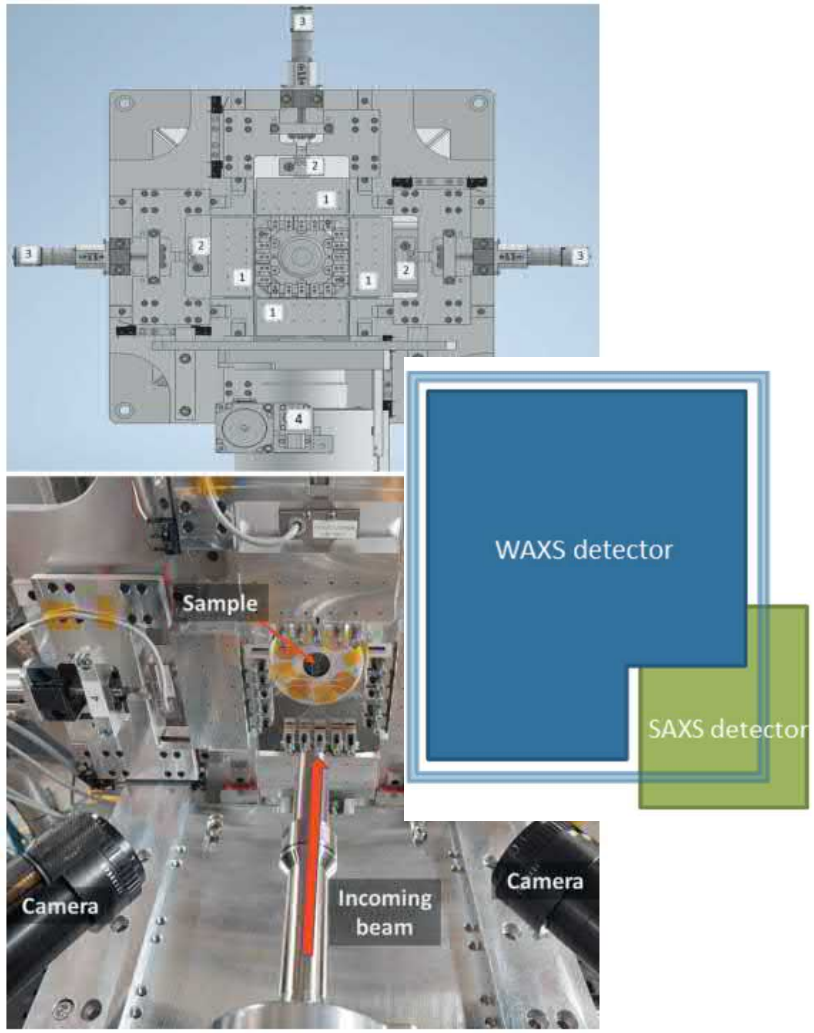
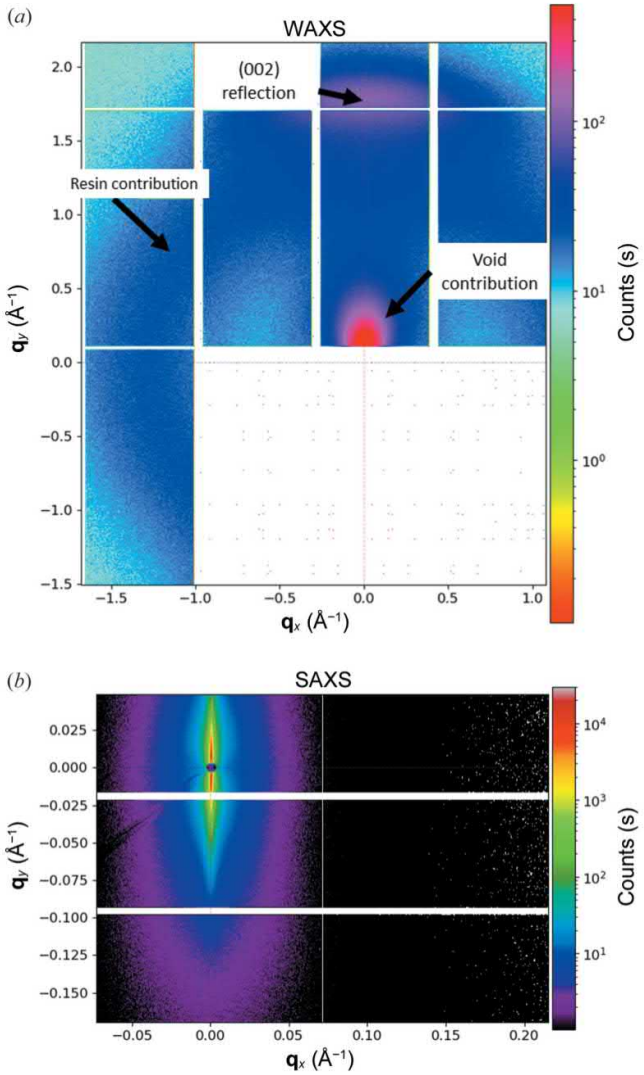
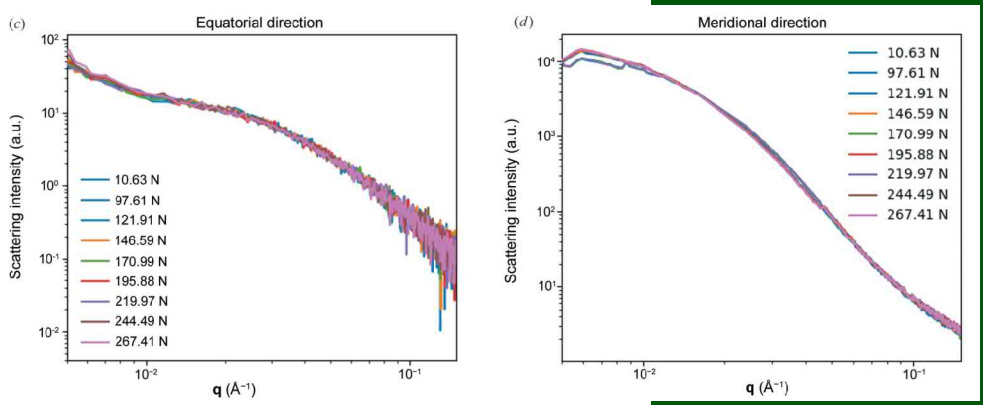


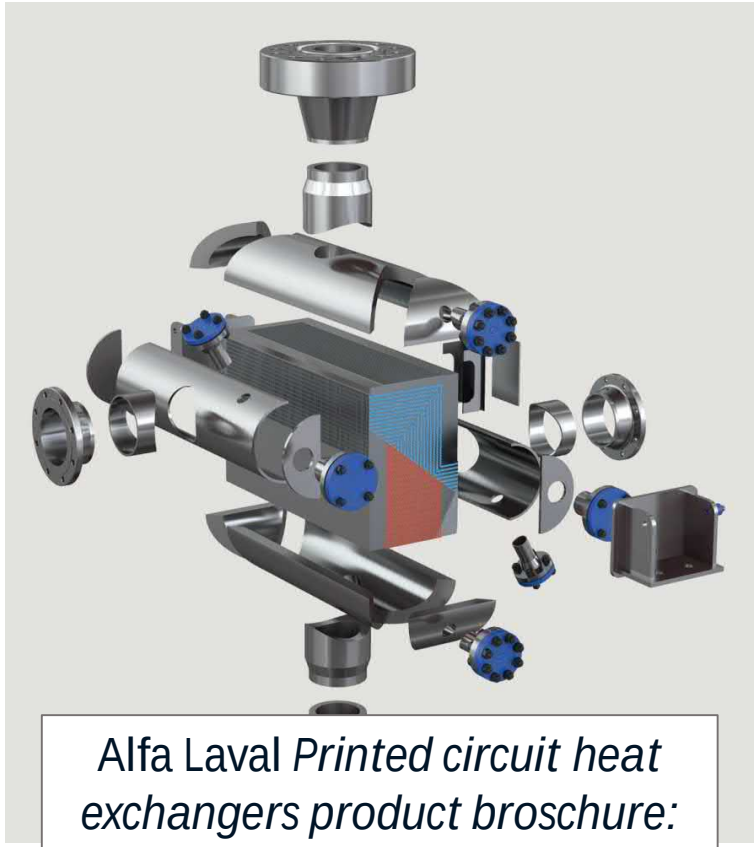




SAXS measurements at different loadings:
no variation in scattering intensity,
no sign of a void volume change

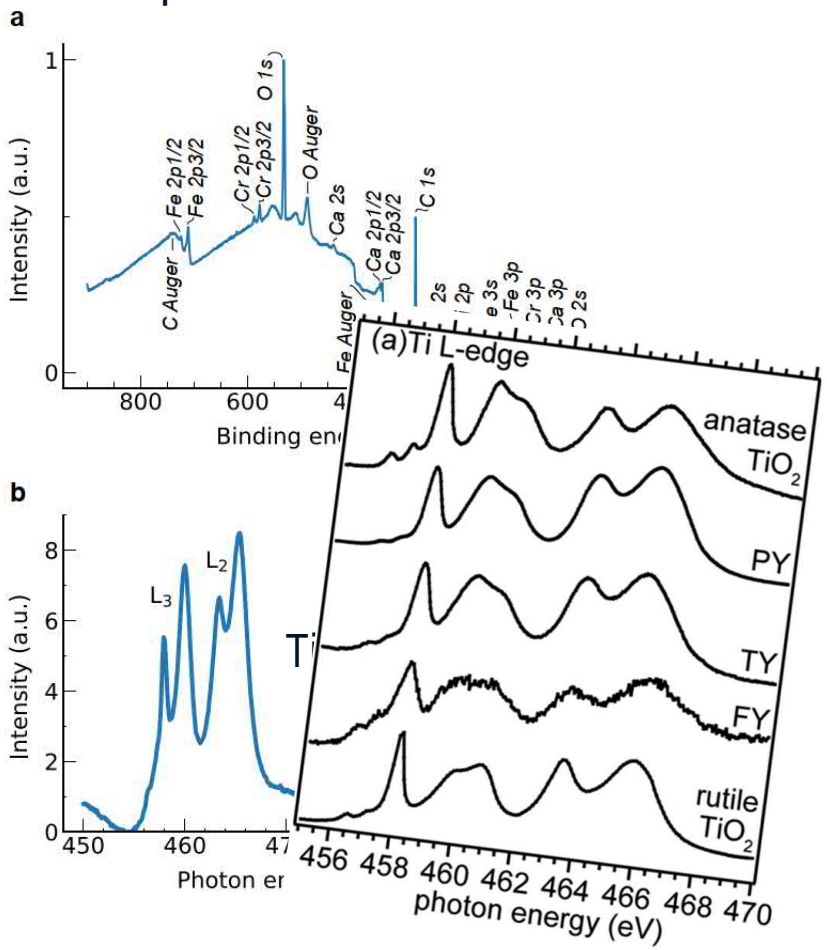
P. Mota-Santiago et al., J. Appl. Cryst. 56 (2023) 967

Diffusion Bonding 321-Grade Stainless Steel: Failure and Multimodal Characterisation @ FlexPES, MAXPEEM (+ SEM (EBSD, EDS), STEM, tensile tests)



Alfa Laval *Printed circuit heat exchangers product broschure:* Stacked microchannel plates joined together by vacuum diffusion bonding

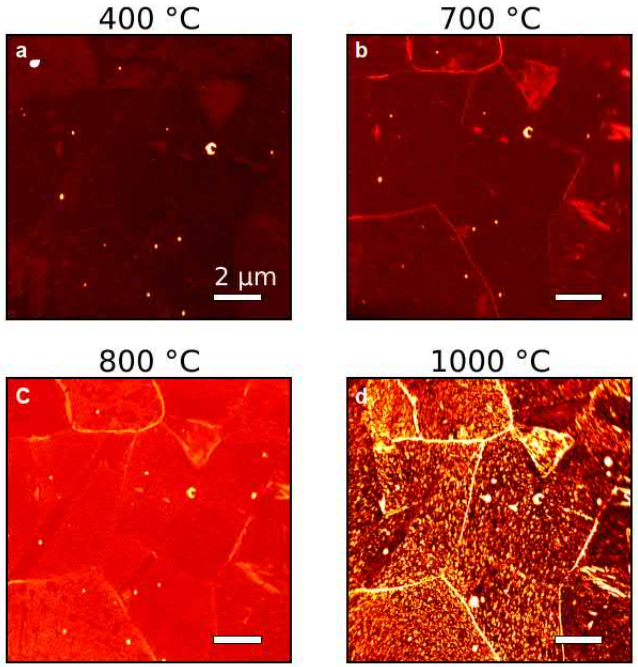
What's there?
Spectroscopic characterisation at RT



I. Lazar et al., Microsc. Microanal. 30 (2024) 192

Diffusion Bonding 321-Grade Stainless Steel: Failure and Multimodal Characterisation @ FlexPES, MAXPEEM (+ SEM (EBSD, EDS), STEM, tensile tests)

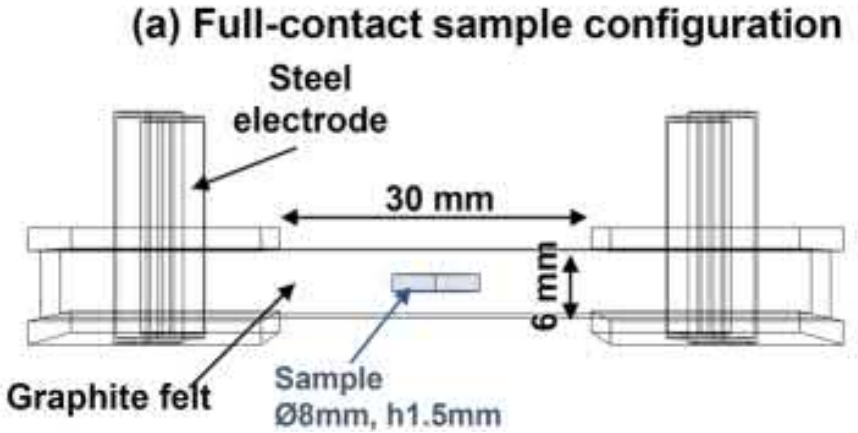
What happens at high temperature?

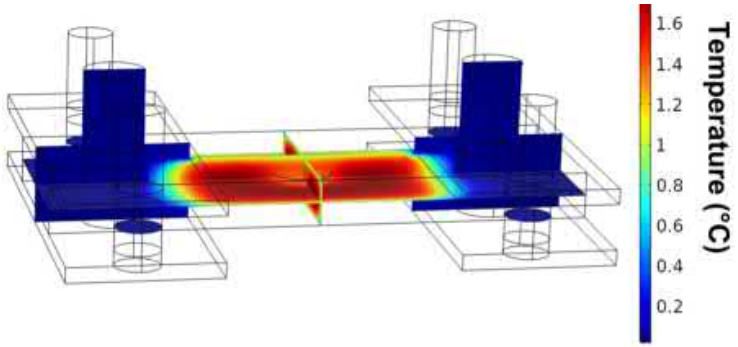


X-ray absorption spectroscopy-photoemission electron microscopy (XAS-PEEM) images at the Ti L-edge on a steel surface at four different temperatures

I. Lazar et al., Microsc. Microanal. 30 (2024) 192

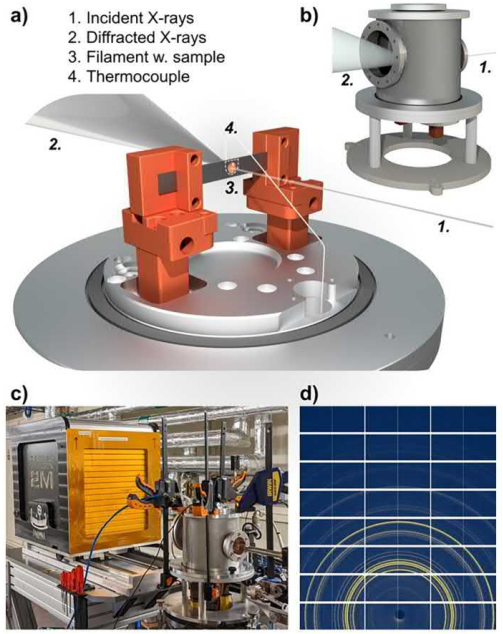
Sintering in seconds, elucidated by millisecond *in situ* diffraction @ DanMAX





Ultrafast high-temperature sintering (UHS)

- Sintering with heating rates of ~10^4 K/min
- Sample embedded in carbon felt
- Is hypothesised to bypass grain growth/coarsening phenoma during nanomaterial sintering



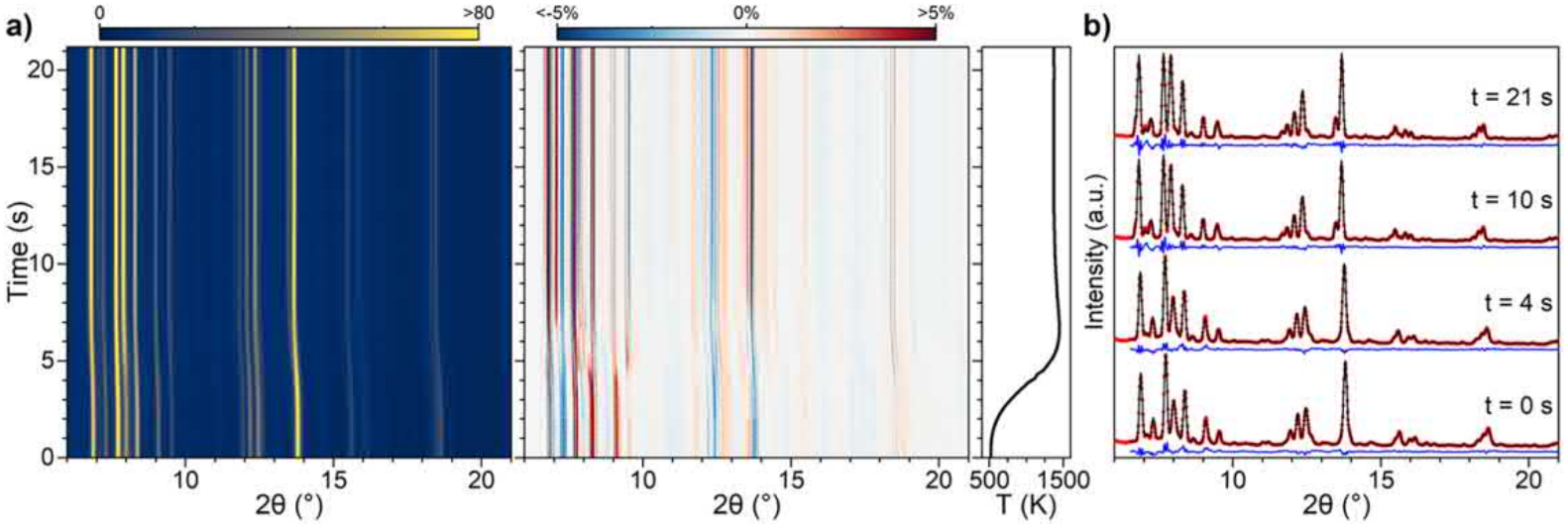
Aarhus Rapid Ohmic Sinteriring (AROS) setup used at DanMAX

Shyam et al., Appl. Mater. Today 35 (2023) 101960

Sintering in seconds, elucidated by millisecond *in situ* diffraction @ DanMAX

Sample: $SrFe_{12}O_{19}$ nanocrystalline powder
Heated to 1373 K @ 150 K/s

5300 frames during 21.2 s
4 ms time resolution



Azimuthally integrated diffraction patterns

Difference of exp. data and sequential Rietveld refinement

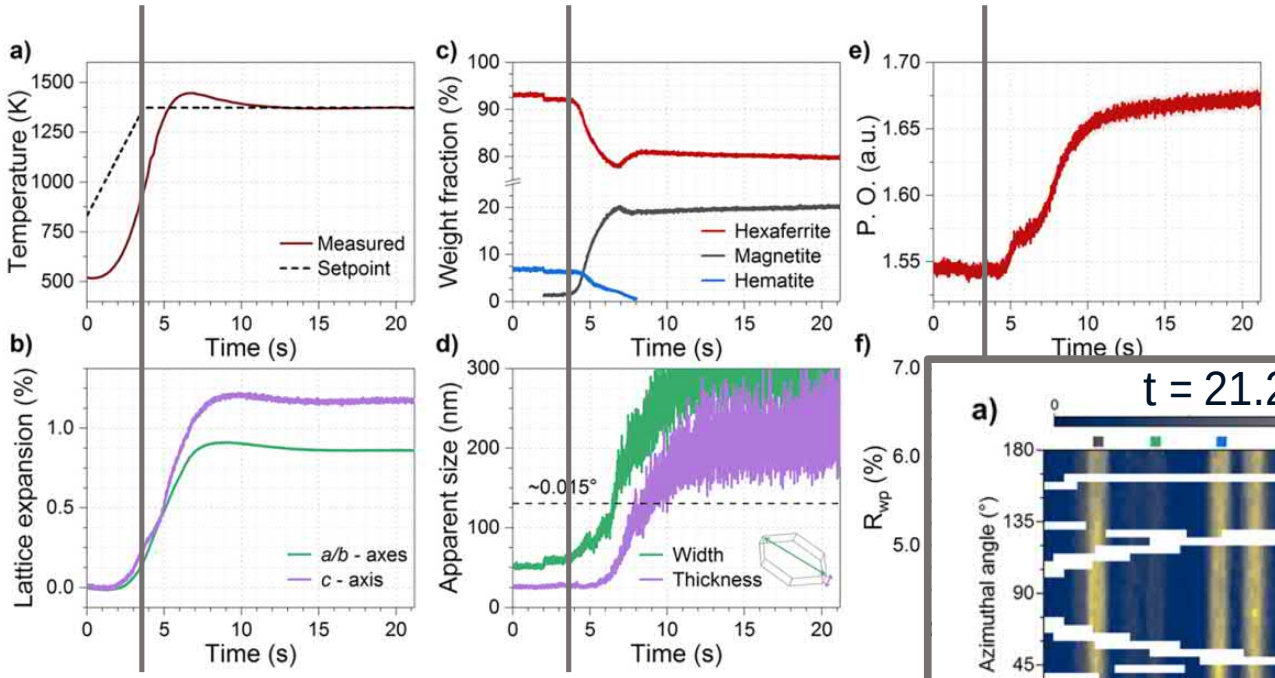
Identified pahses:
$SrFe_{12}O_{19}$ (hexaferrite)
α-Fe_2O_3 (hematite)
Fe_3O_4 (magnetite)

Shyam et al., Appl. Mater. Today 35 (2023) 101960

Sintering in seconds, elucidated by millisecond *in situ* diffraction @ DanMAX

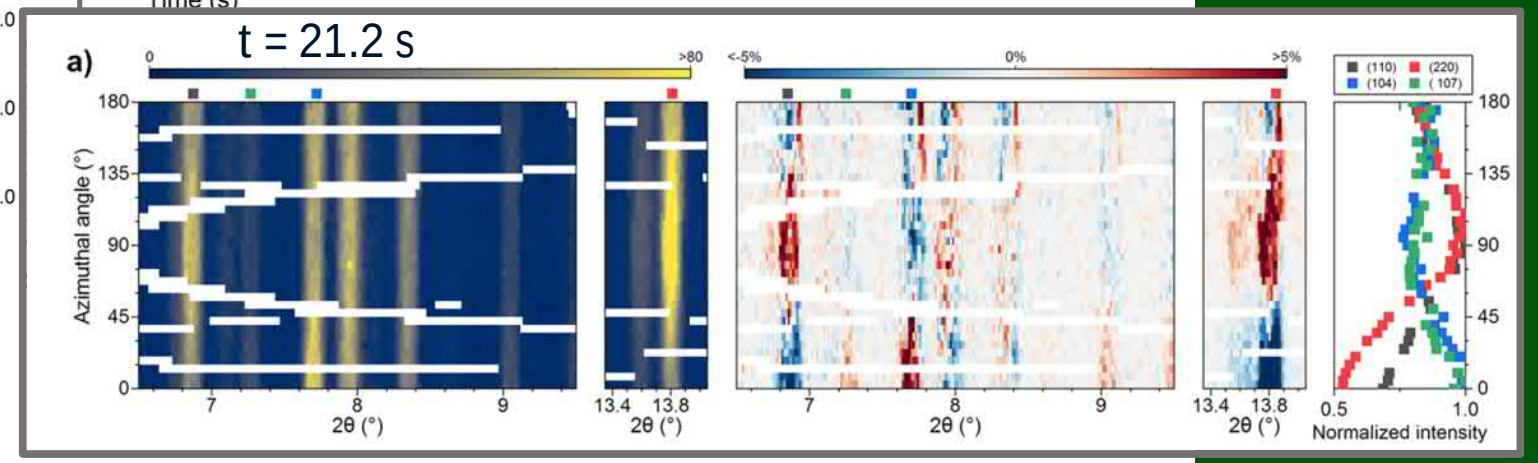
Compositional change

Change of texture



Anistropic expansion

Crystallite growth



Shyam et al., Appl. Mater. Today 35 (2023) 101960

MAX IV
Annual Report 2023
with Science Highlights

ADVANCED MATERIALS

A promise realised for memory storage with antiferromagnetic spintronics

MAXPEEM

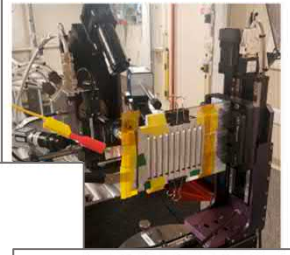
In the realm of device memory applications with spintronics, antiferromagnets are a promising advancement to achieve significantly faster writing speeds (Terahertz range). The alternating alignment of their microscopic magnetic moments creates zero net magnetisation.

Research led by Johannes Gutenberg University Mainz in Germany explored the so-called current pulse driven Néel vector rotation, performing a current pulse induced manipulation of the orientation of the axis along which the alternating magnetic moments of the antiferromagnet Mn$_2$Au

ENERGY MATERIALS

Revealing structural degradation for Li-ion batteries optimisation

DanMAX



Improving the performance of Li-ion batteries by reducing degradation is a highly sought aim for expanded commercial use. Scientists at the Technical University of Denmark (DTU) performed an operando study of four prototype NMC811/Si–Gr 5Ah multilayered pouch cells (manufactured by Cidetec), a type of LI-ion battery. They endeavoured to understand the behaviour of Si–Gr (silicon graphite) anodes in conjunction with NMC811 cathodes.

Spatial and time resolved X-ray diffraction (XRD) measurements at MAX IV's DanMAX beamline were used to 2D-map the battery cathode and anode lithiation/delithiation, and volume expansion across the cell.

The tests provided information about structural changes during intercalation/deintercalation and spatial lithium inventory, and its relation to battery degradation. Results showed significant inhomo-

ADVANCED MATERIALS

Unusual electron pairing gives clue to high-temperature superconductivity

Bloch

have studied the antiferromagnetic electron-doped high-temperature super-
rates are well-known model systems with strongly interacting
al phenomena, including unconventional superconductivity.

materi-
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e low energy
components.
the expected

ADVANCED MATERIALS

Way forward for studying 2D antiferromagnets opens for applications

MAXPEEM

A research team has recently found an effective way of probing two-dimensional antiferromagnets. They investigated the magnetic configuration and spin-correlation coupling effects of VPS_3 through optical routes. Moreover, an interlayer exciton–magnon coupling is observed in the two-dimensional heterointerface of monolayer semiconductor WSe_2 – few-layer antiferromagntic insulator VPS_3. The result opens up for further investigations on using two-dimensional antiferromagnets for opto-spintronics or antiferromagnet-based quantum information technologies.

Two-dimensional antiferromagnets were just recently discovered and seem to be promising materials for information storage devices. They have been challenging to study because they do not have a net magnetic moment. The difficulties of detecting the antiferromagnetic order and manipulating the correlated magnetic coupling behaviour has been a seemingly insurmountable barrier, limiting their further applications.

CATALYSIS

Protective layer preserving catalyst material for energy conversion

HIPPIE

A team of Norwegian researchers has taken important steps towards development of a reliable photocatalyst for power-to-chemical applications. They have used a tantalum nitride, Ta_3N_5, photocatalyst and found how a nickel oxide coating, NiOx, can protect the surface against corrosion in harsh conditions.

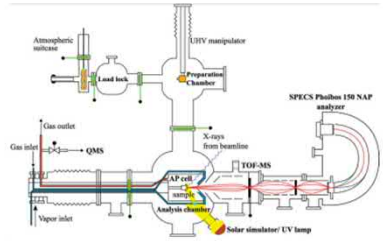
Photocatalysts convert photons to electrons and holes, thus storing solar energy into chemical. One example is photo-electrolysis of water, where the catalyst materials absorb light to split water into hydrogen and oxygen. It is the "Holy Grail" of photocatalysis, a long running research field.

INSTRUMENTATION

Photocatalytic setup for in situ and operando Ambient Pressure X-ray Photoelectron Spectroscopy

SPECIES

The capabilities of the Ambient Pressure X-ray Photoelectron Spectroscopy (APXPS) endstation at the SPECIES beamline have been extended by a novel photocatalytic setup. The instrumentation allows the study of solar radiation-driven processes by combining external light sources with the APXPS measurements. In situ and operando experiments can be carried out with the setup under mbar pressure ranges, which often approach realistic scenarios in either industry or nature. The development of the setup is the result of a collaboration between MAX IV and the University of Oulu, Finland.



Schematic of the experiment setup.

As a case study, we have investigated the photocatalytic hydrogen evolution reaction, which is a promising technique for harvesting and storing solar energy into chemical energy and has been

Download the report

A Swedish Research Infrastructure:

User Facility that provides access to modern X-ray analytical tools.

Researchers come to MAX IV in two principal ways:

1 Peer reviewed access → Open calls twice per year → Apply for beamtime → Proposals ranked on scientific merit → Beamtime for free → Need to publish peer-rev. papers

Open to all users (academic, industrial) for free via a peer-reviewed proposal system based on scientific merit. Two (2) proposals calls per year.
Users agree to publish results, using open access.

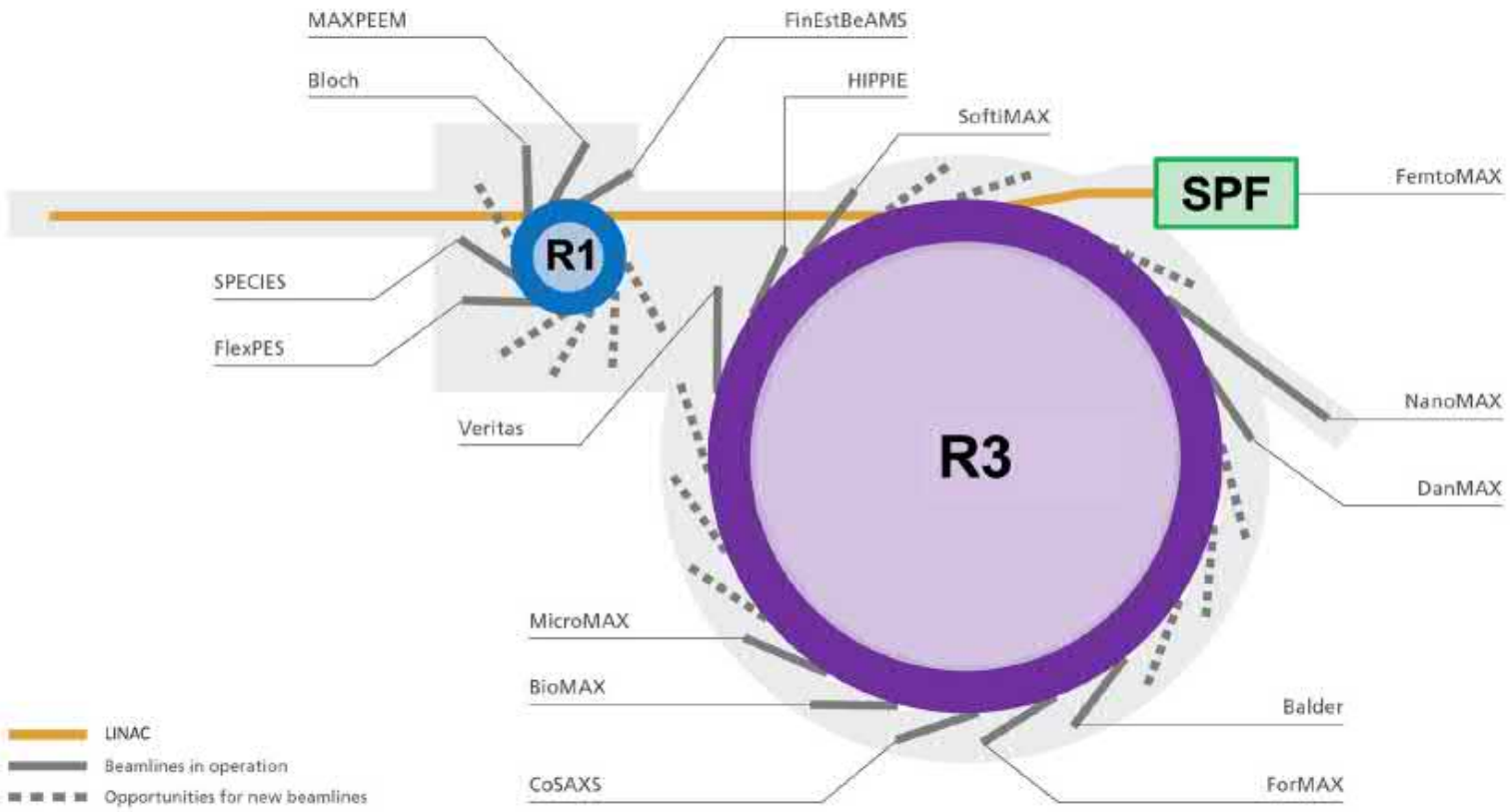
Always discuss with the beamline scientists while preparing the proposal !

2 Proprietary access → Short term: fast access → Long term framework agreement → Confiden-tiality agreement → Fees for beamtime and services → Results belongs to the buyer

Proprietary users pay MAX IV *(at cost-recovery for the operations)* for the time used and own their results.

Access to MAX IV

Always discuss with the beamline scientists while preparing the proposal !



Contacts: see beamline homepages
https://www.maxiv.lu.se/BEAMLINENAME

Access to MAX IV

Always discuss with the beamline scientists while preparing the proposal !

One more way to come to MAX IV: Fast access

Beamline	Sample Feasibility	Standard Measurement Service	Max shifts	Accepting proposals
Balder	Yes	Yes	2	Yes
BioMAX	Yes	No	2	Yes
BioMAX - FragMAX	No	Yes	6	Yes
Bloch	Yes	No	6	Yes
CoSAXS	Yes	Yes	1	Yes
FemtoMAX	Yes	No	6	Yes
FinEstBeAMS, Solid-state Endstation	Yes	Yes	6	Yes
FlexPES	Yes	Yes	2	Yes
HIPPIE	Yes	Yes	SF: 6 SMS: 3	Yes
MAXPEEM	Yes	No	6	Yes
MicroMAX	Yes	No	6	
NanoMAX	Yes	No	6	
SoftiMAX	Yes	No		Yes
SPECIES	Yes	Yes (APXP only)	SF: 6 SMS: 3	Yes
Veritas	Yes	No	6	Yes

https://www.maxiv.lu.se/user-access/access-modes/fast-access/

Access to MAX IV

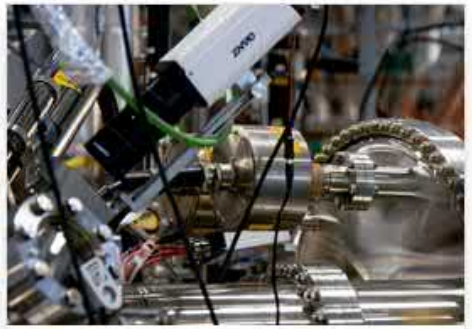
"Fast access: scientific experiment" on its way back

Always discuss with the beamline scientists while preparing the proposal !

If you're a potential user:
it's always a good idea to team up with existing users
(if you don't know any – ask us)

Nyttiggörande av neutron- och synkrotronljusanläggningar

Stänger 21 sep 2021



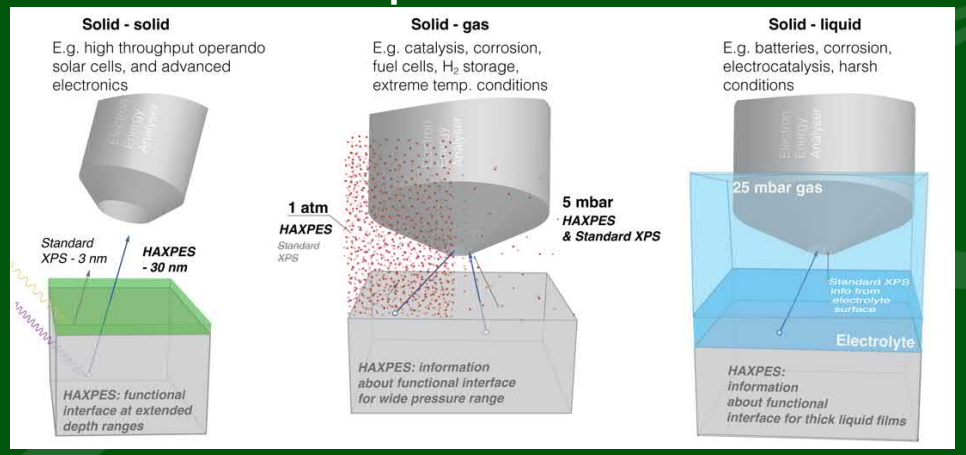
Ökat nyttiggörande av neutron- och synkrotronljusbaserad teknik

Stänger 12 sep 2023

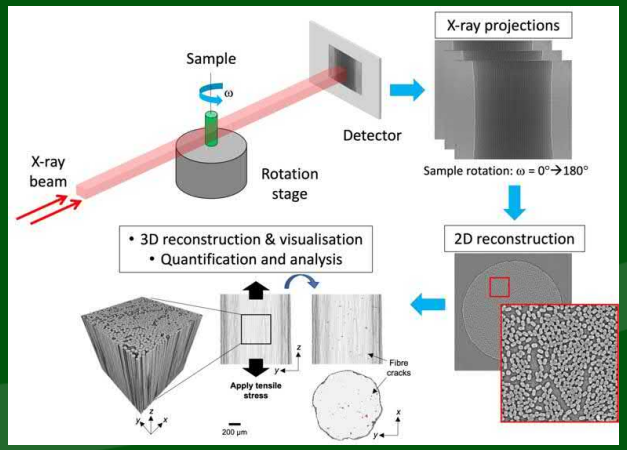
Access to MAX IV

Moving towards the future

SpectroWISE



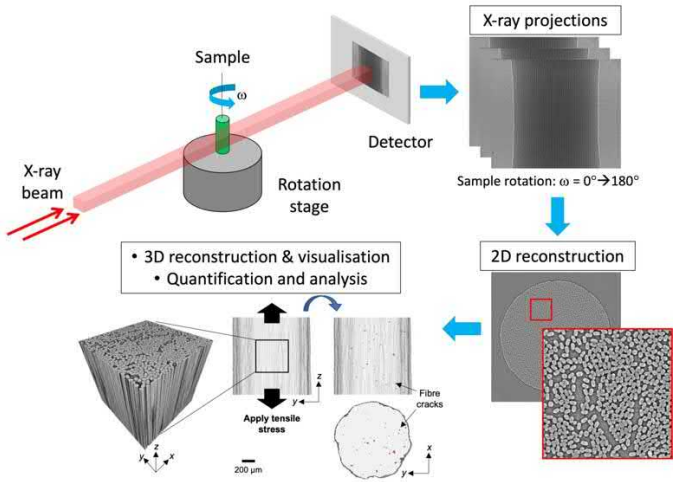
TomoWISE



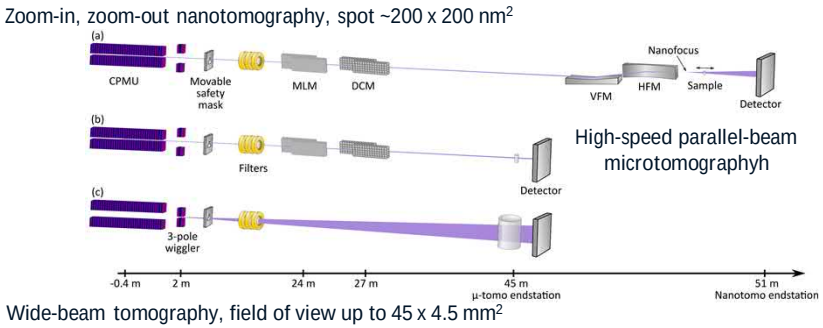
MAX 4U

MAX IV

Time-resolved materials tomography at many lengthscales



TomoWISE operation modes

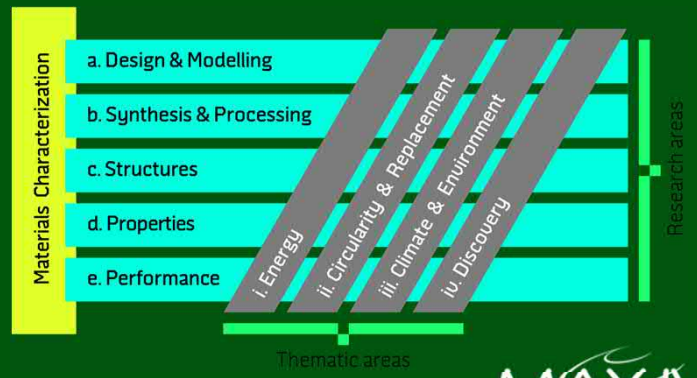


X-ray sources	(i) Cryogenic permanent magnet undulator, 14 mm period, 2.0 m magnetic length (ii) 3-pole wiggler, 3 T maximum field
Energy range	20-65 keV
Monochromators	(i) Multilayer monochromator (ii) Double-crystal monochromator (iii) Filtered white beam option
Focusing optics	Multilayer Kirkpatrick-Baez mirrors
Detection system	Scintillator + microscope
Beam size on sample	200 x 200 nm^2 – 45 x 4.5 mm^2 (h x v)
Tomography acquisition rate	Up to 1 kHz
Flux @45 keV	Up to 10^{14} ph/s/mm^2

TomoWISE:

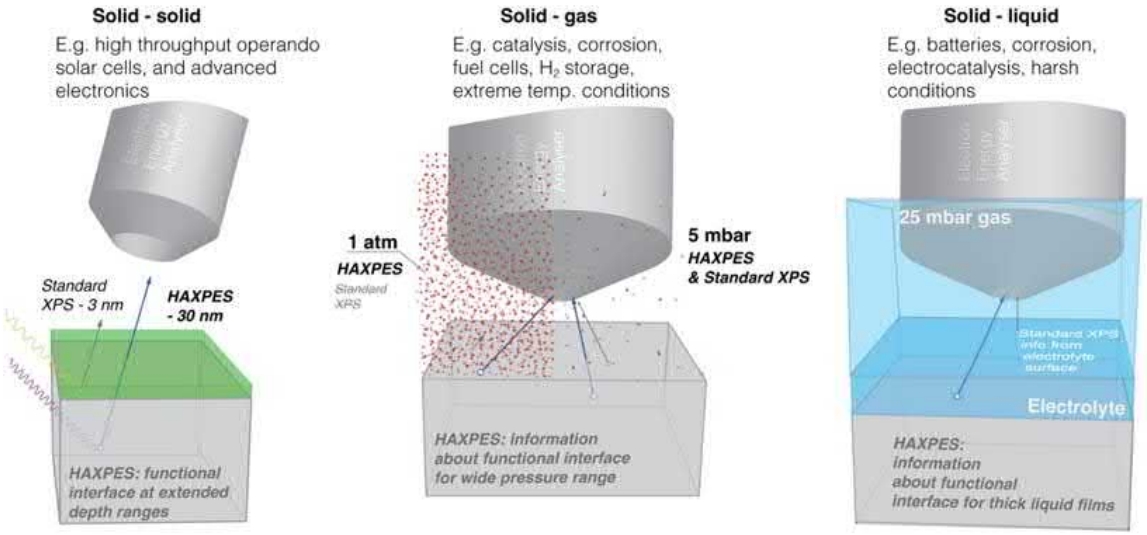
Tomographic imaging of materials over many lengthscales and with temporal resolution

TomoWISE technical design report (TDR) funded by WISE (Wallenberg Initiative Materials Science for Sustainability)



MAX IV

HAXPES for the study of interfaces in materials

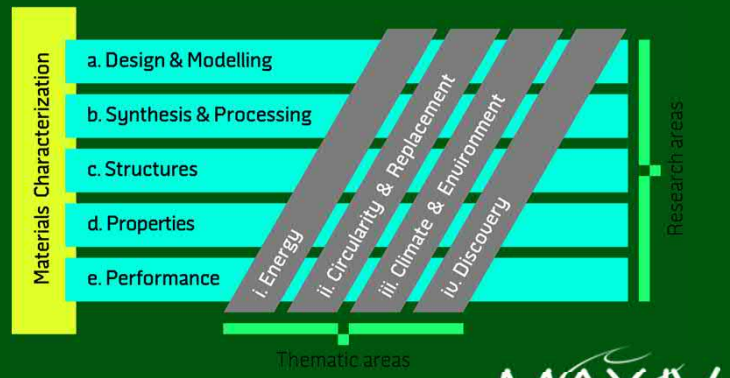


X-ray source	In-vacuum undulator, 20 mm period, 3 m magnetic length
Energy range	2.1–15 keV
Monochromator	Double-crystal monochromator Channel-cut high-resolution monochromator
Energy resolution	<400 meV (2-4 keV), <200 meV (4-15 keV)
Focusing optics	Horizontal first focusing mirror, Kirkpatrick-Baez mirrors for focus onto sample. Bendable mirrors to allow for defocusing.
Beam size on sample	<3 x 3 μm^2 to >200 x 200 μm^2
End station 1	UHV-HAXPES
End station 2	1-bar HAXPES or electrochemistry HAXPES (exchangeable), or open port
Flux @8 keV	Up to 10^{14} ph/s

SpectroWISE:

HAXPES (Hard x-ray photoelectron spectroscopy) for the study of interfaces

SpectroWISE technical design report (TDR) funded by WISE (Wallenberg Initiative Materials Science for Sustainability)




MAX 4U

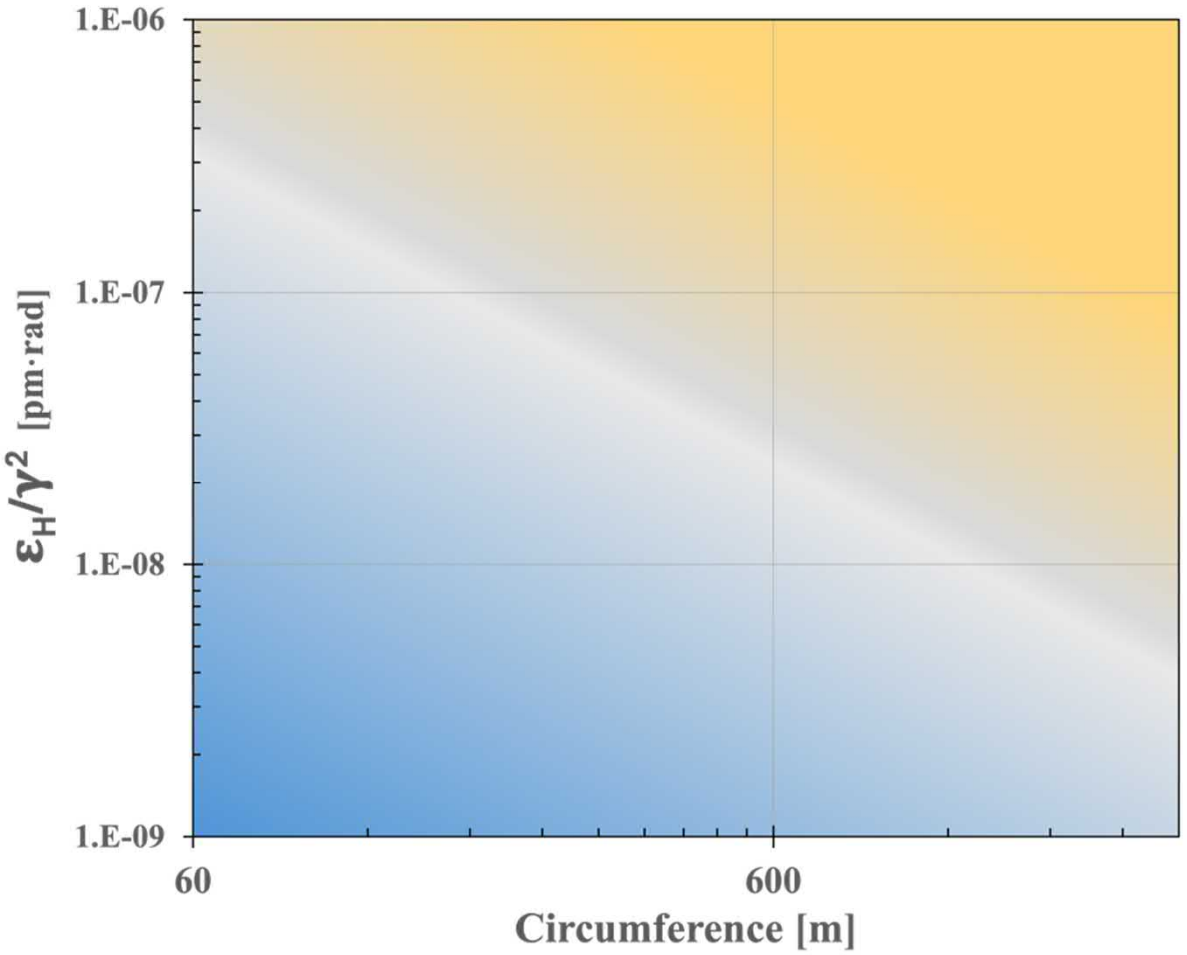
Accelerators

1.5 GeV Storage Ring

- C = 96 m , $\mathcal{E} \backsim 6$ nmrad
- Diffraction-limited X-rays at 16 eV
- World-leading source of soft X-rays

3 GeV Storage Ring

- C = 528 m , $\mathcal{E} \backsim 328$ pmrad
- Diffraction-limited X-rays at 300eV
- First 4th generation storage ring



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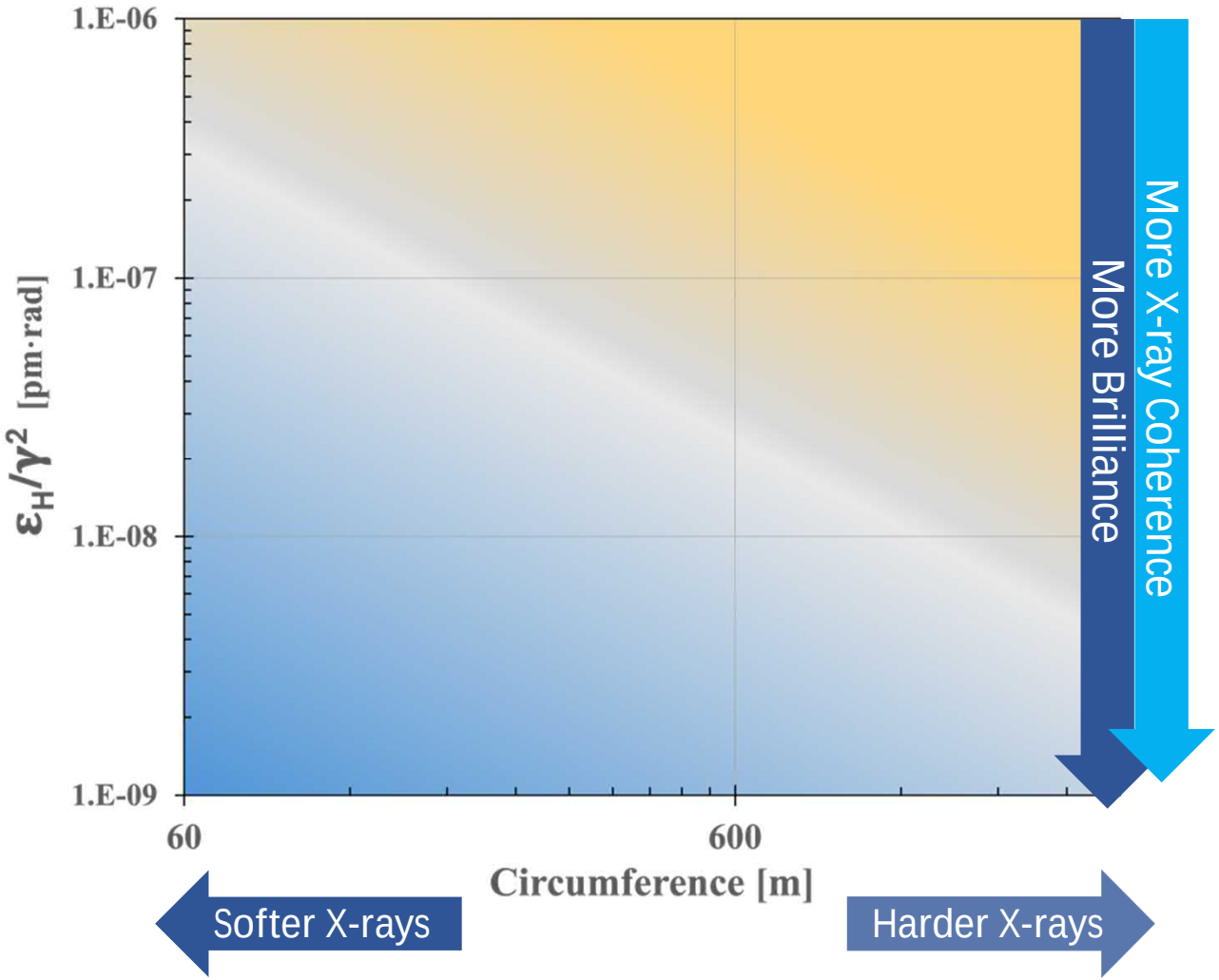

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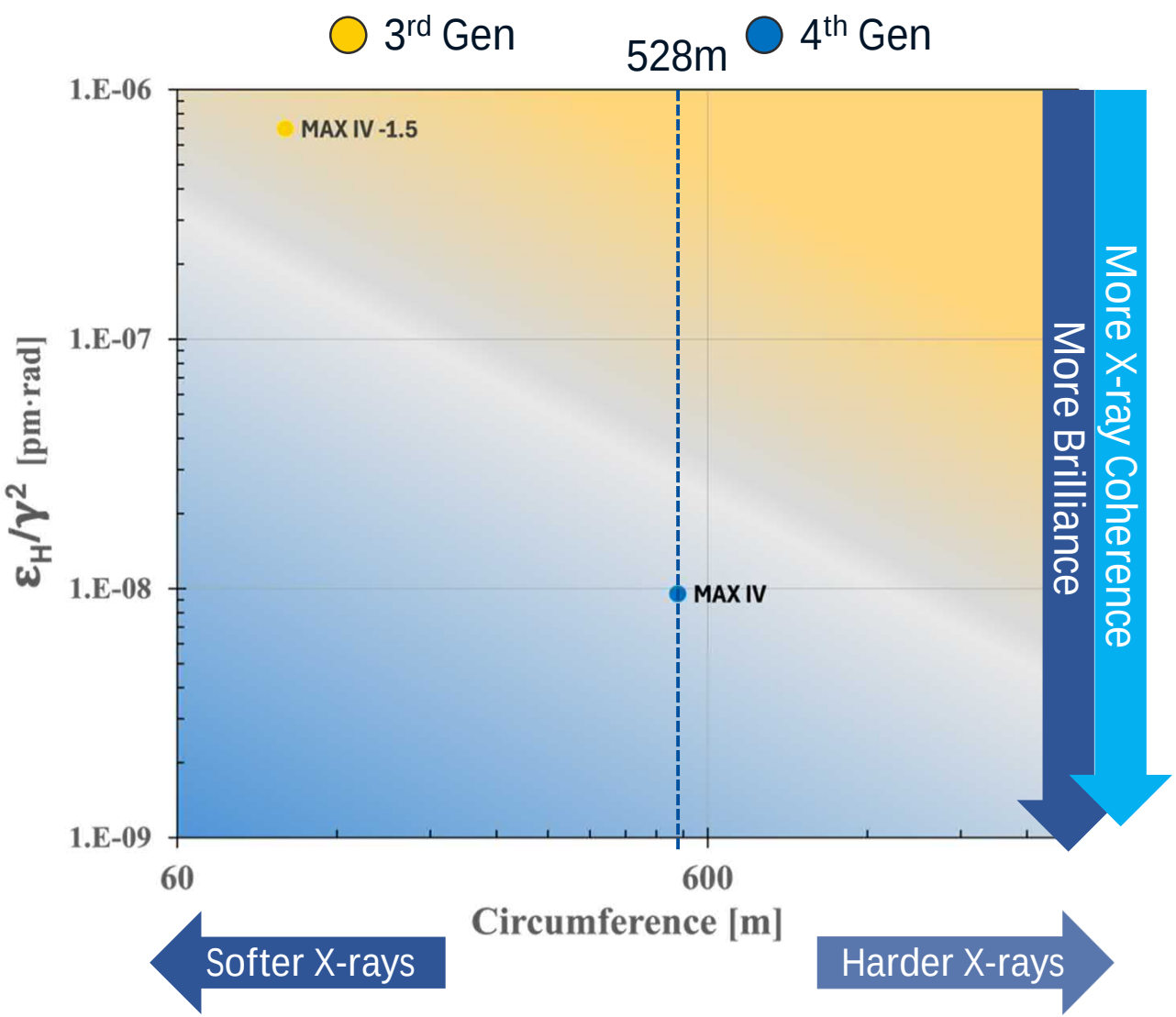

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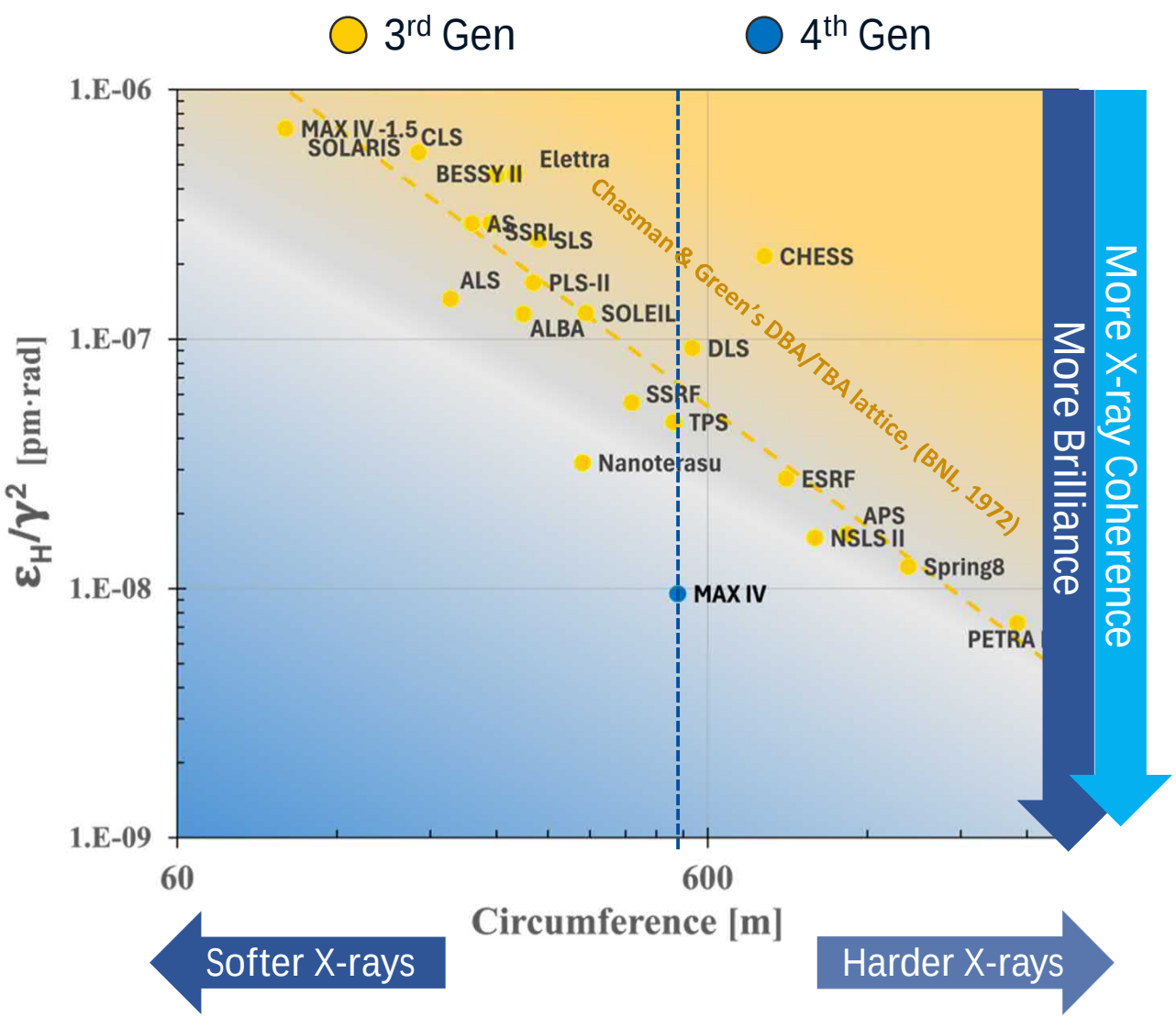


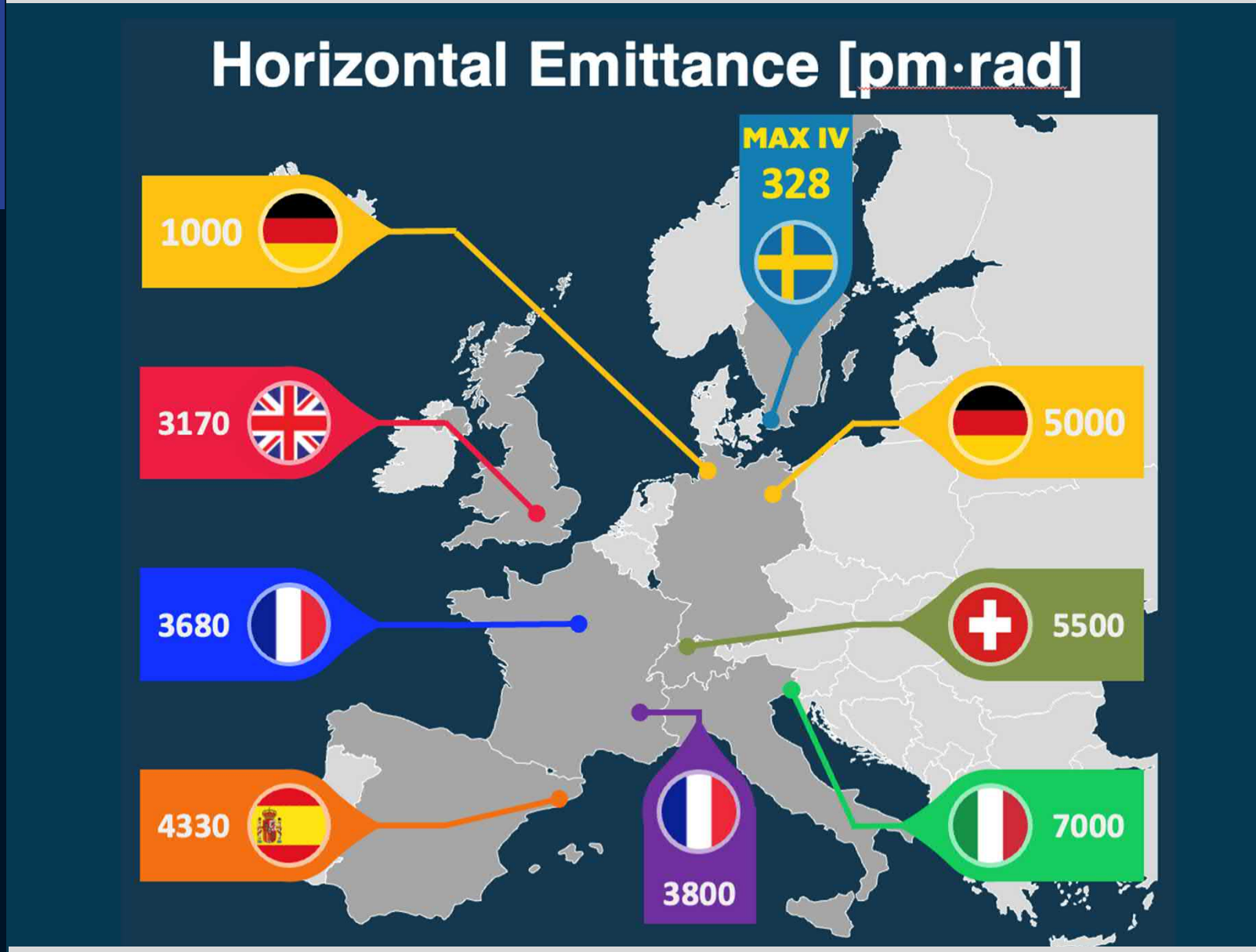
In 2016

MAX IV

European context in 2016

MAX IV 3Gev Ring: The first 4th generation synchrotron Source

Breaking down the emittance glass ceiling with world record emittance of 328pmrad



A factor 3 to 20 better than a ALL htsources

Accelerators

MAX IV

Emittance

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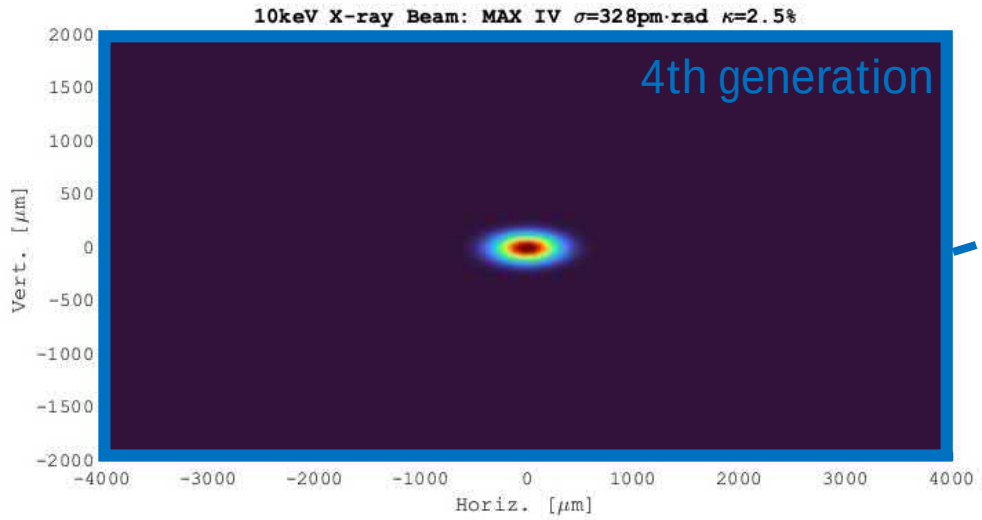

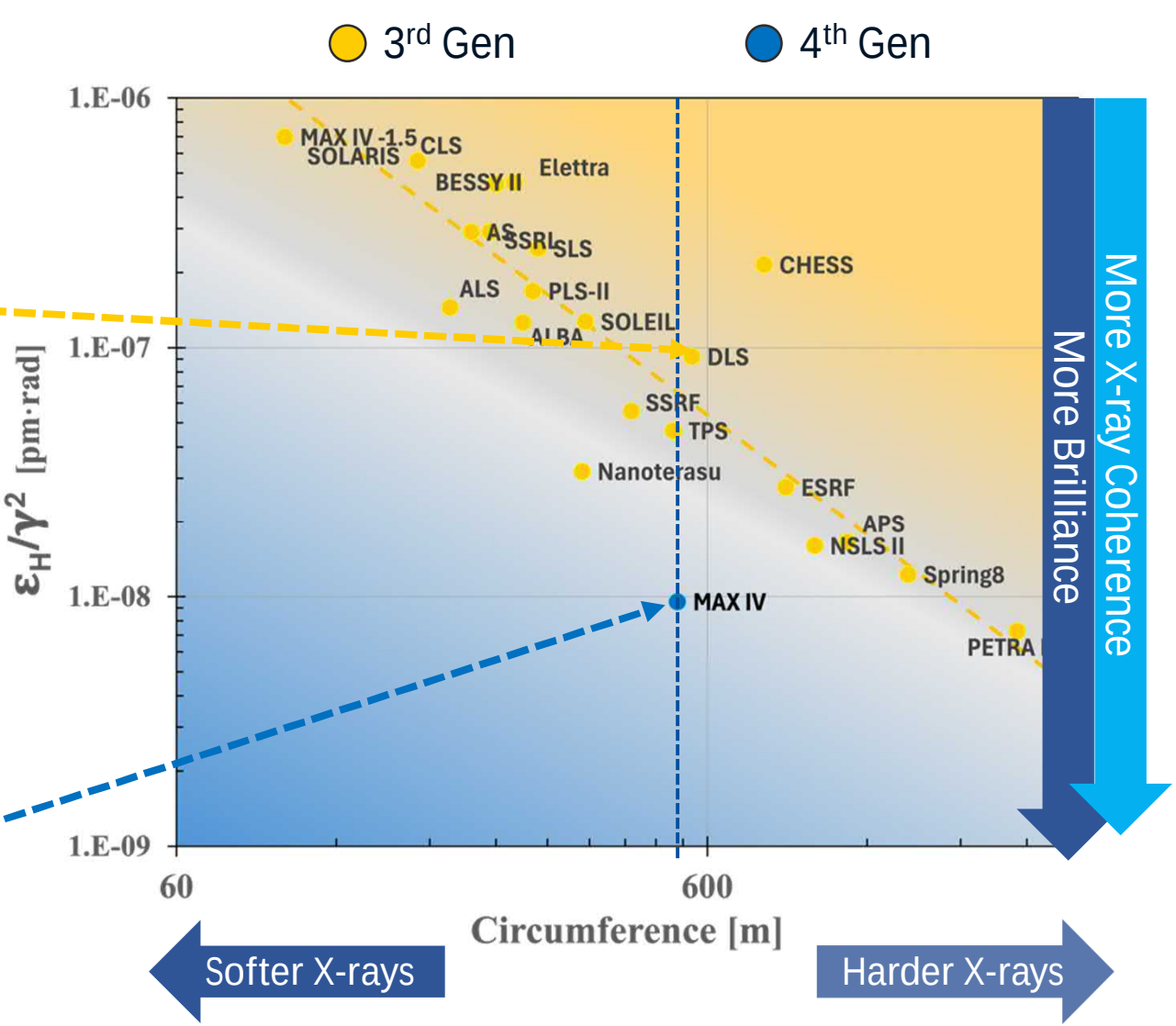

In 2016

10 keV beam profile 20 meters from the source, same scale

Accelerators

MAX IV

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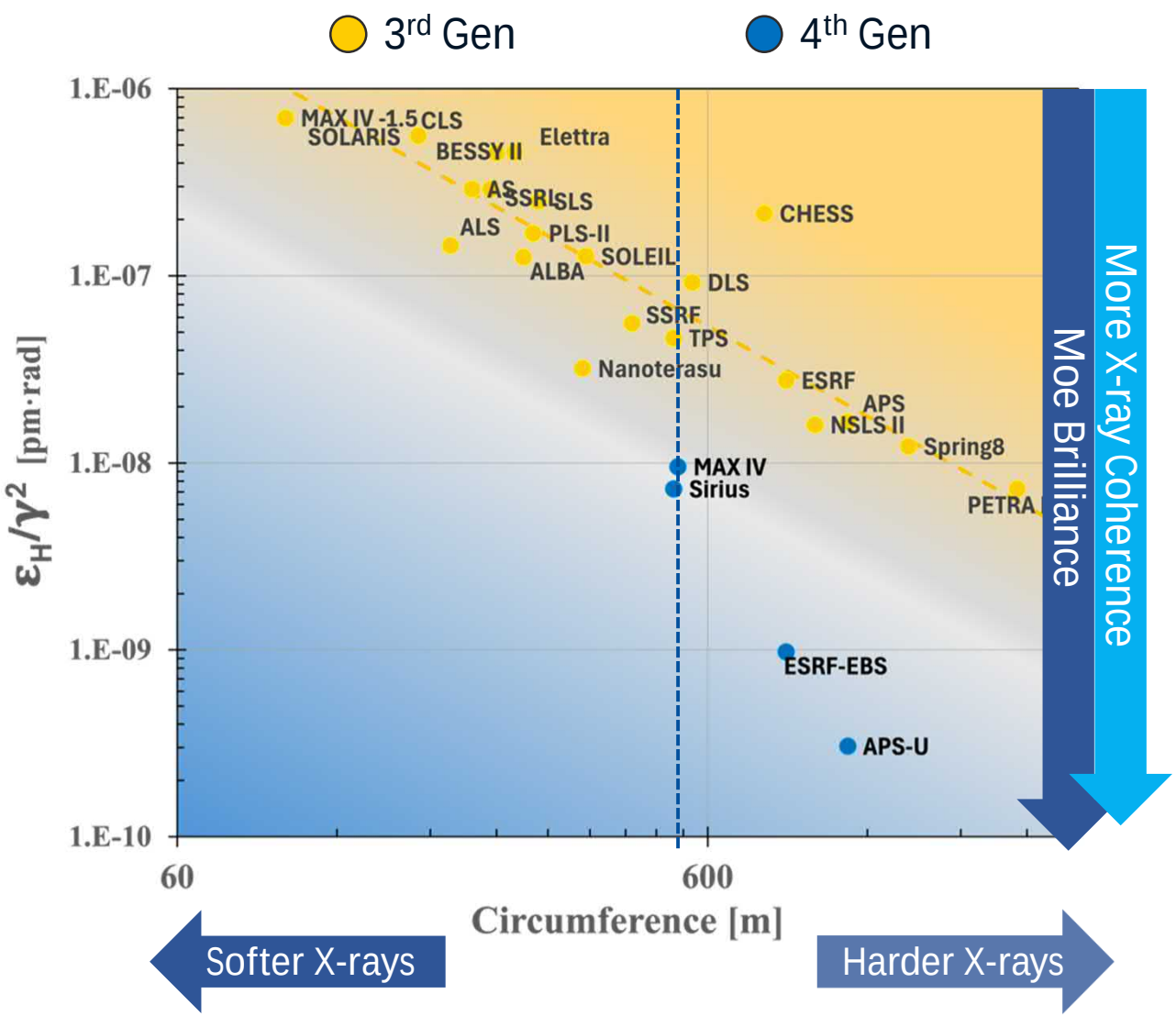

Today

Accelerators

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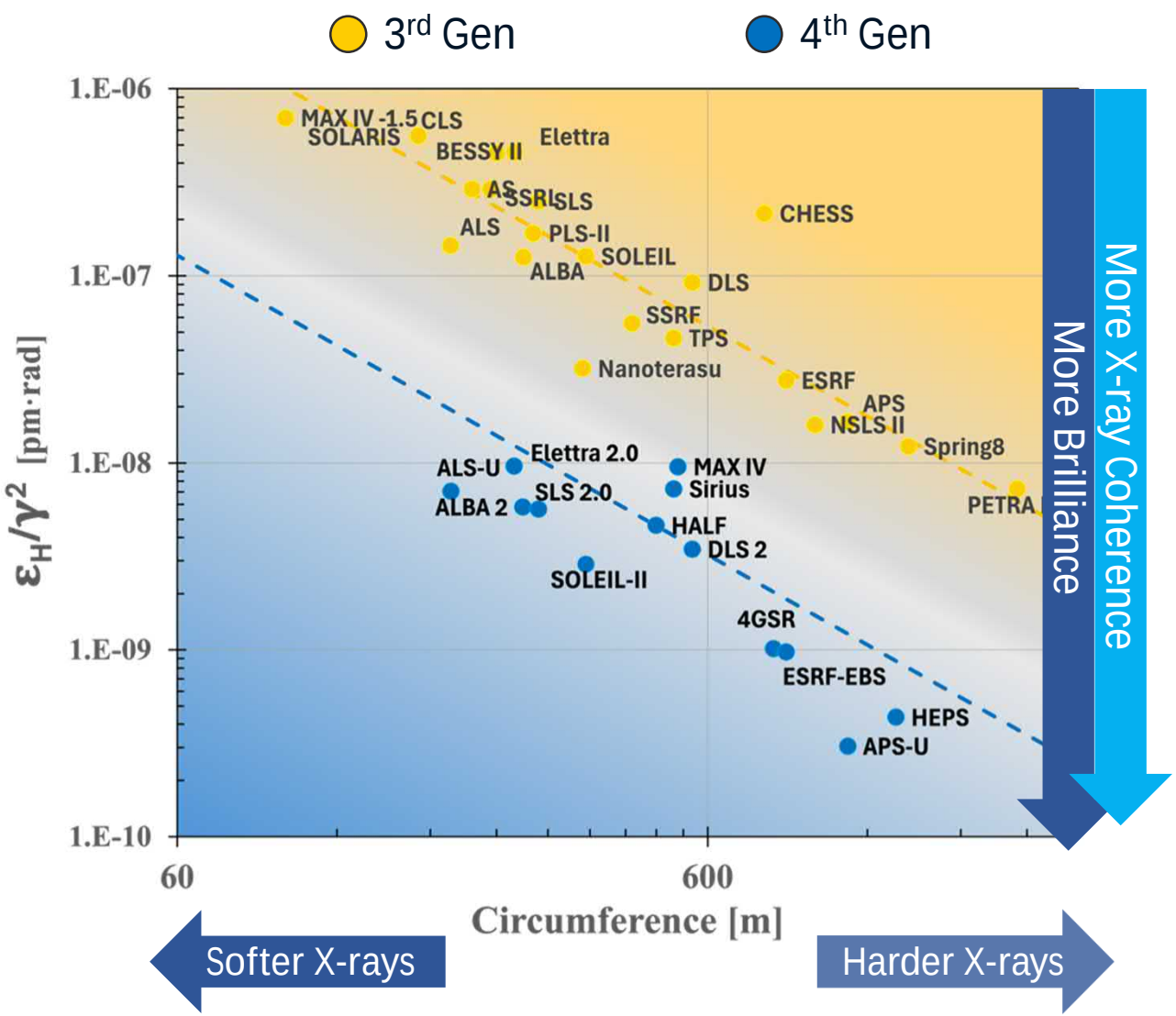

Most 4th generation light sources will be fully operational by the end of the decade

By 2030

Accelerators

MAX 4U

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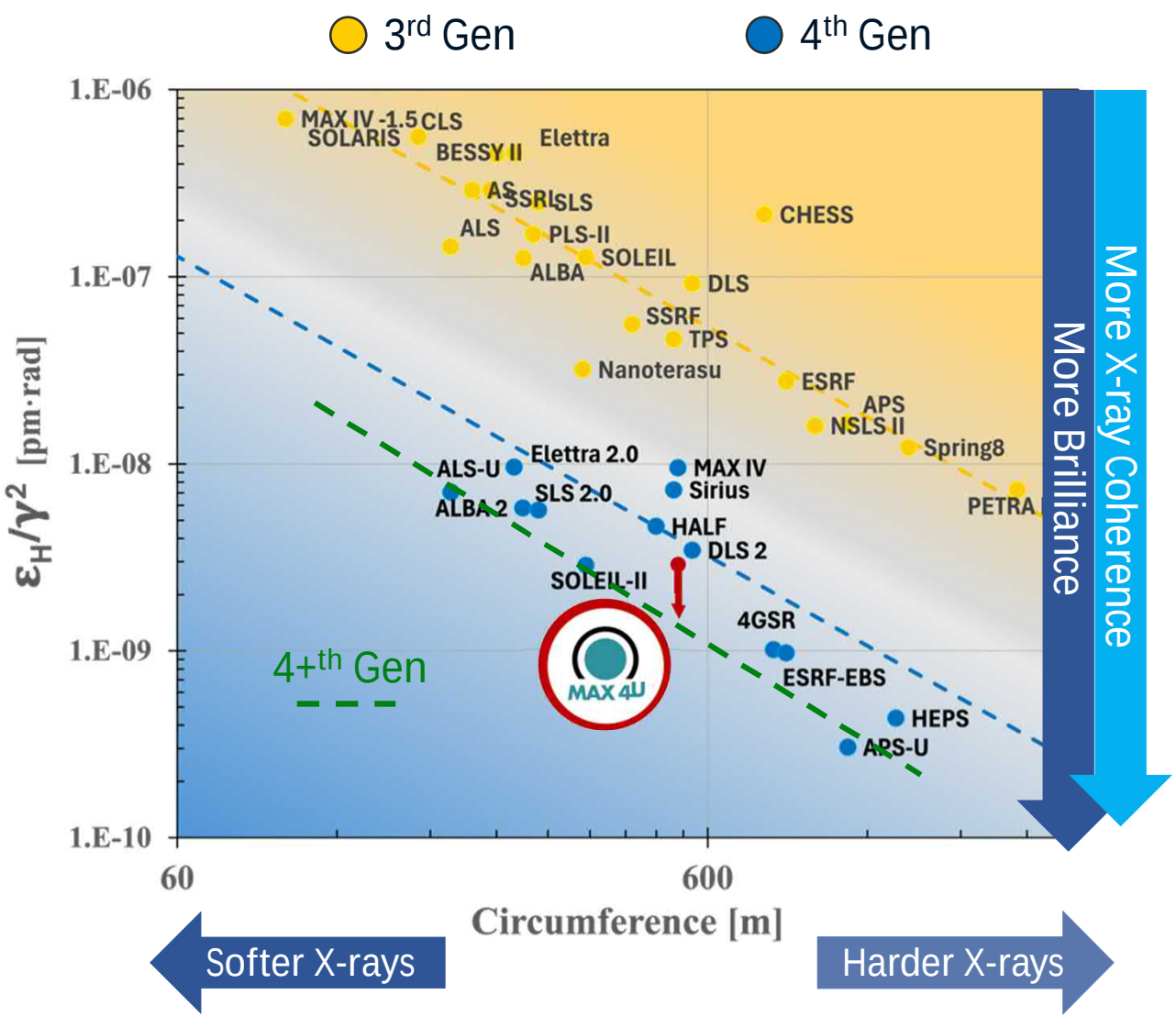


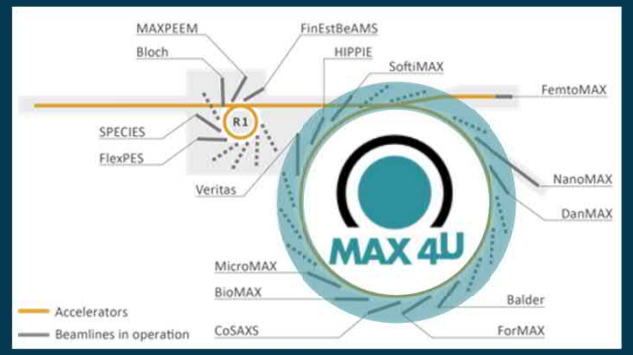
Most 4th generation light sources will be fully operational by the end of the decade

Toward 2030 ⇒ MAX §

MAX 4U – A ”surgical” upgrade of our 3GeV ring

MAX 4U

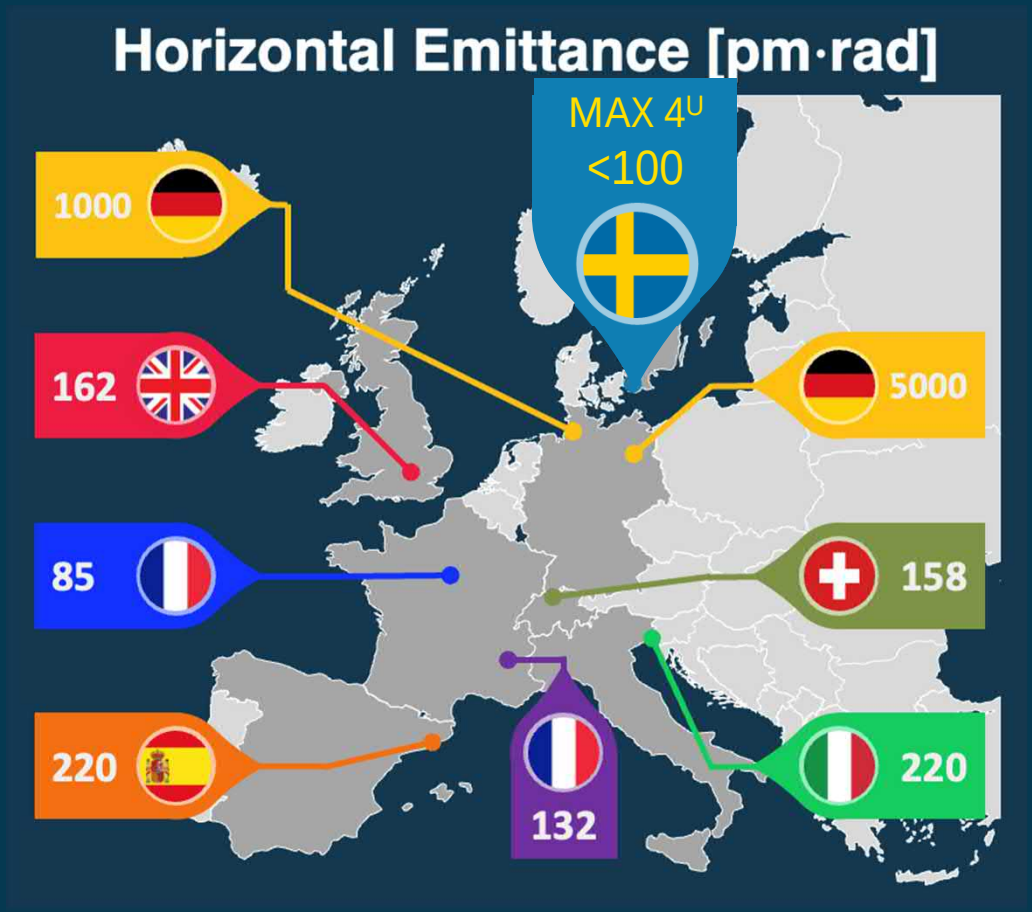
Ensuring leadership of Swedish research with X-rays for the next decades



Optics parameters for a candidate MAX 4U lattice

Parameter	Value
Energy	3 GeV
Circumference	528 m
Bare Lattice Emittance	<100 pmrad

Funded synchrotron light source upgrades and operating facilities in 2030



Very welcome to MAX IV!

www.maxiv.lu.se

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