Synchrotron light facility updates:
The bright future of synchrotron science

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Advanced Photon Source Director

U.S. DEPARTMENT OF ENERGY
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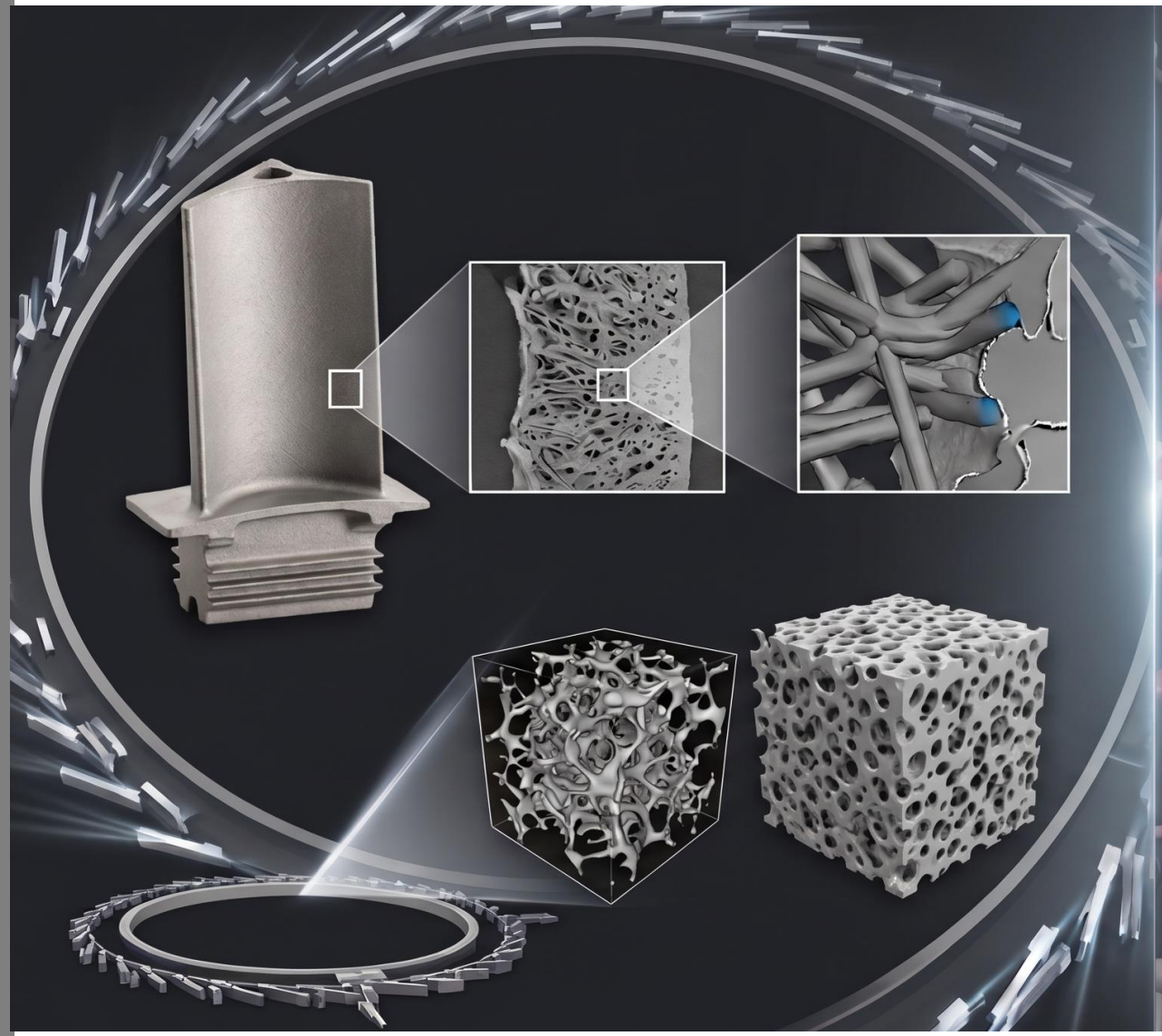
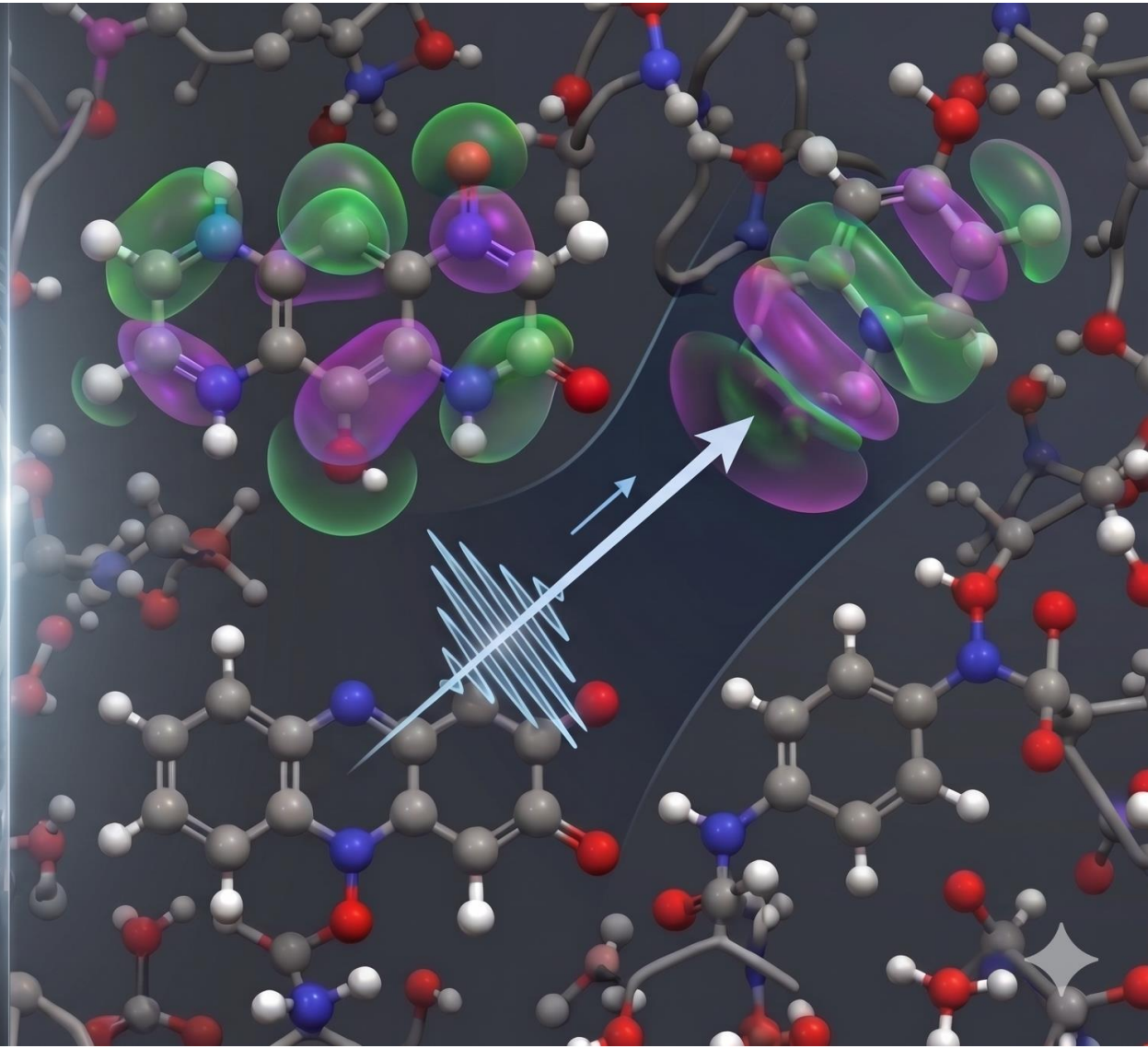
Argonne NATIONAL LABORATORY | APS

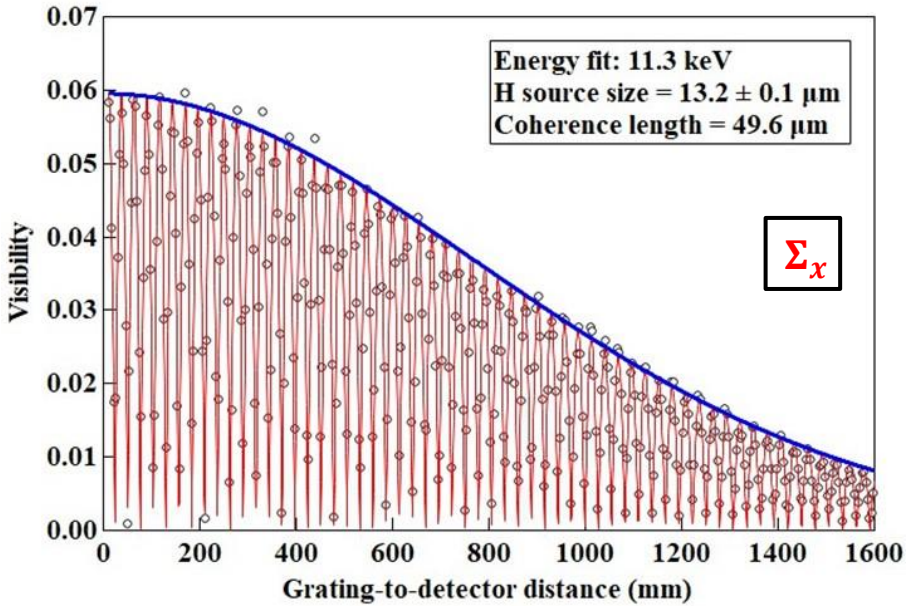
X-ray Science – Unveiling the architecture of matter across scales

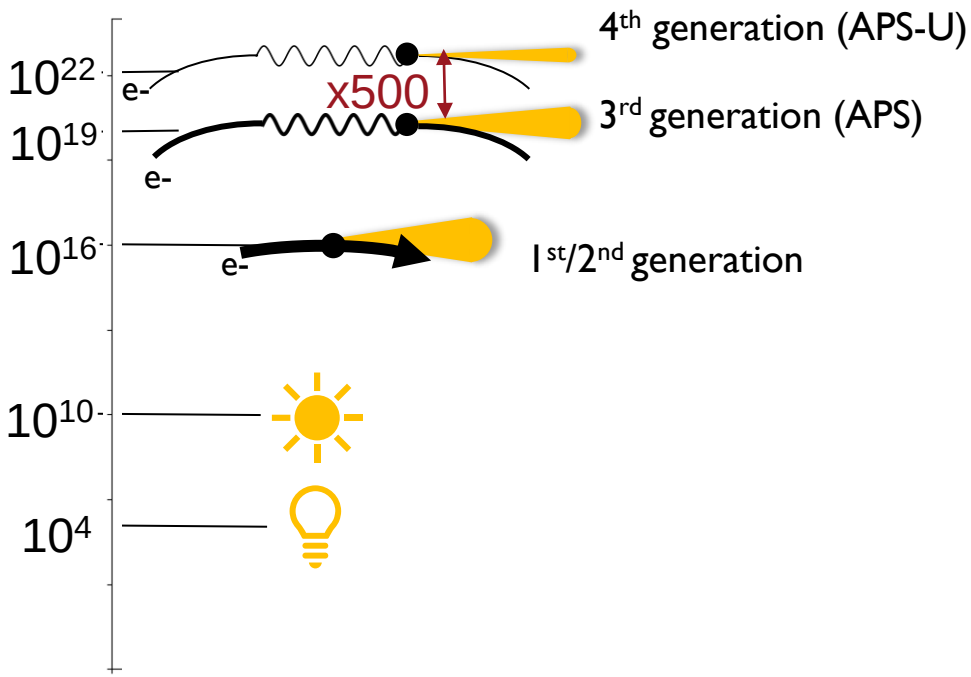




APS-U

Emittance: ~30pm, full coupling

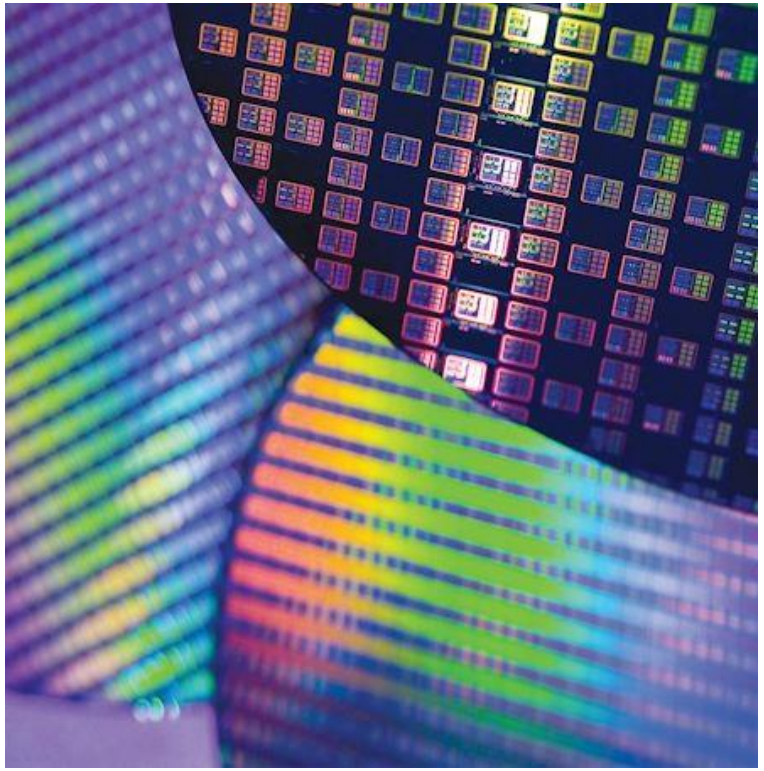




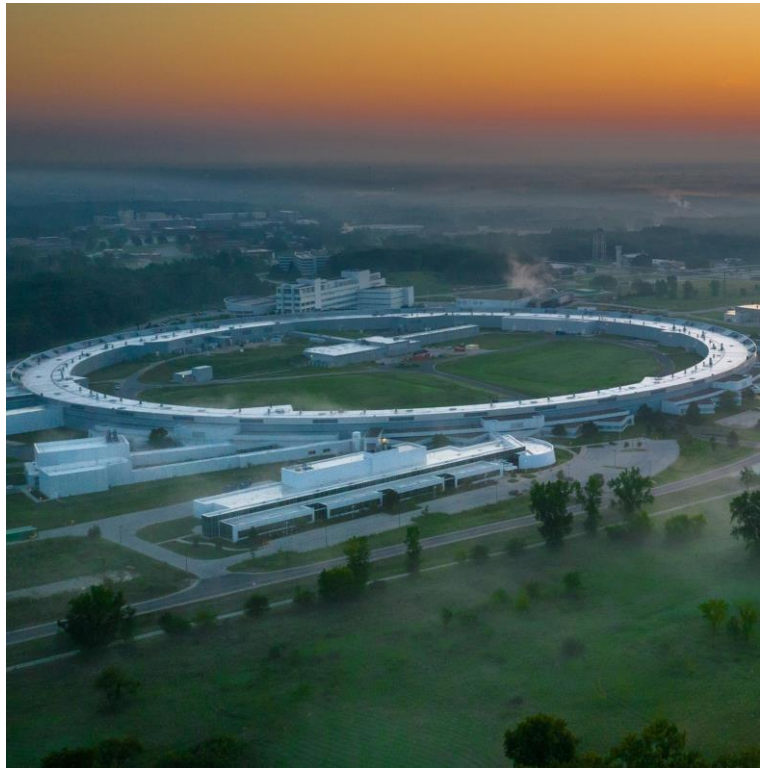
Shi, X., Lin, Y.-C., Zhao, J., Toellner, T., Hu, M. Y., Seifert, S., Lee, B., Grizolli, W., Wojcik, M. J., Rebuffi, L., Assoufid, L. & Sajaev, V. (2025). J. Synchrotron Rad. 32, 1152-1161.

Not bad for parasites

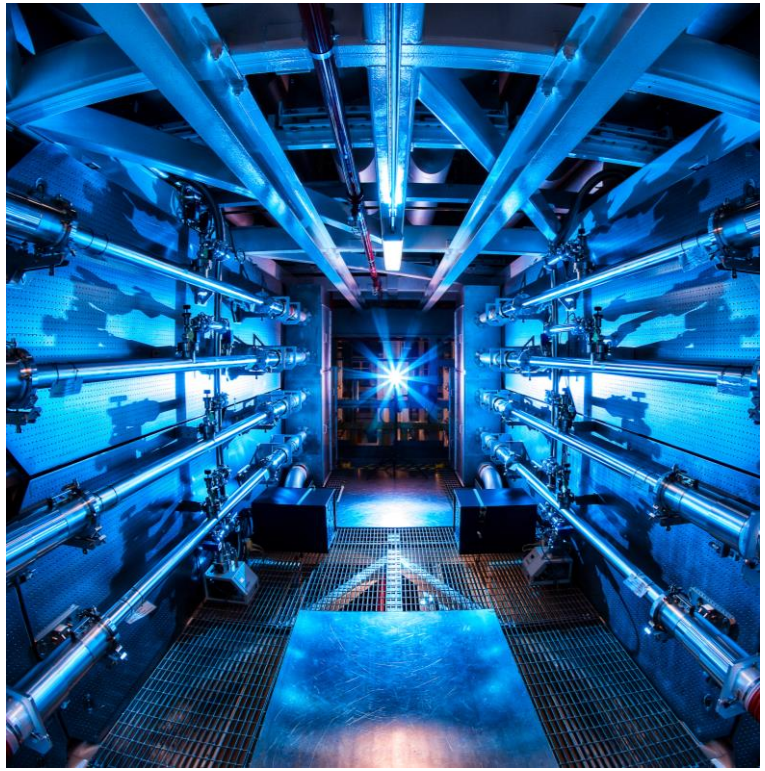
Semiconductor density
From 3000 to 10^{11}
($x10^{7}$)



Storage ring brightness
From 10^{13} to 10^{22}
($x10^{9}$)



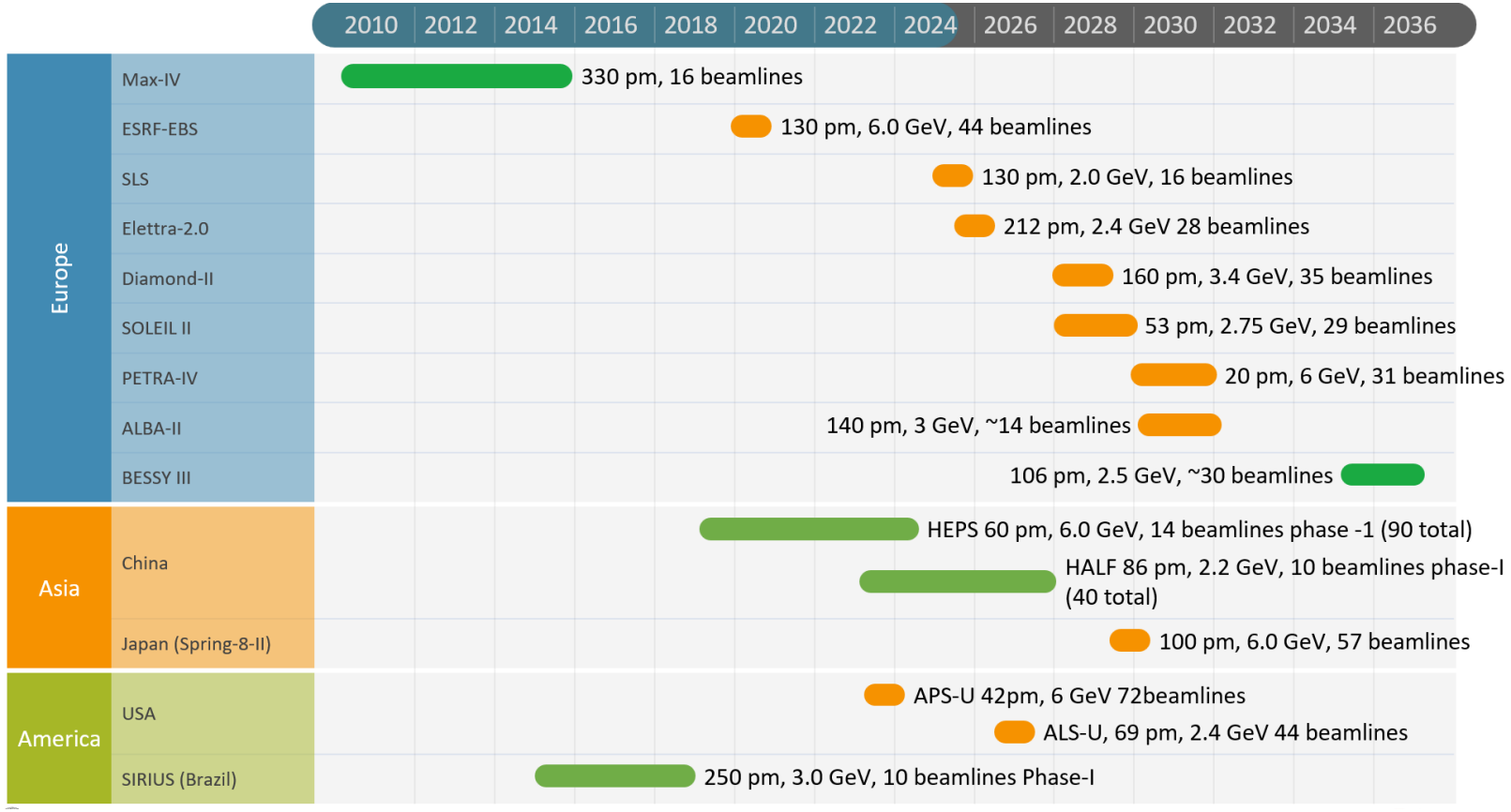
Laser Peak Power
From mW to PW
($x10^{18}$)



Transition to 4th gen storage rings

Horizon 2040:

- ~20 4th gen rings worldwide
- >550-600 beamlines



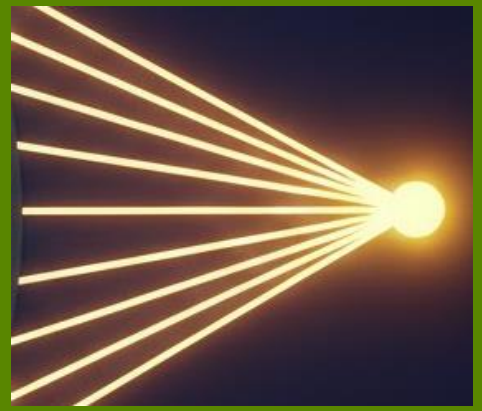
Improvements

APS upgrade has transformed our ability to probe complex systems

SPATIAL COHERENCE

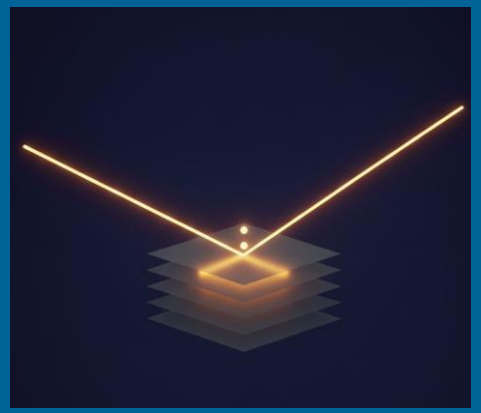
Decode disordered and complex systems

FOCUSING



Can focus X-ray beams down to 20 nanometers

HARD X-RAYS

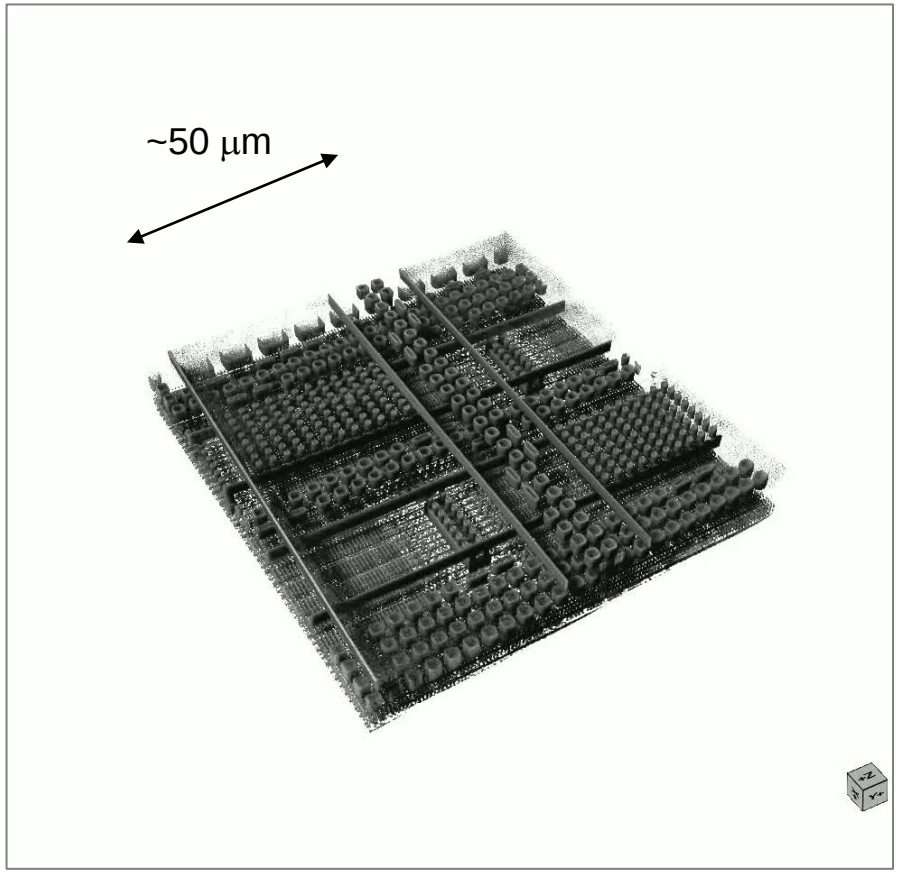


APS ability to penetrate dense objects continues

Microelectronics

Coherent beam improves spatial resolution and speed

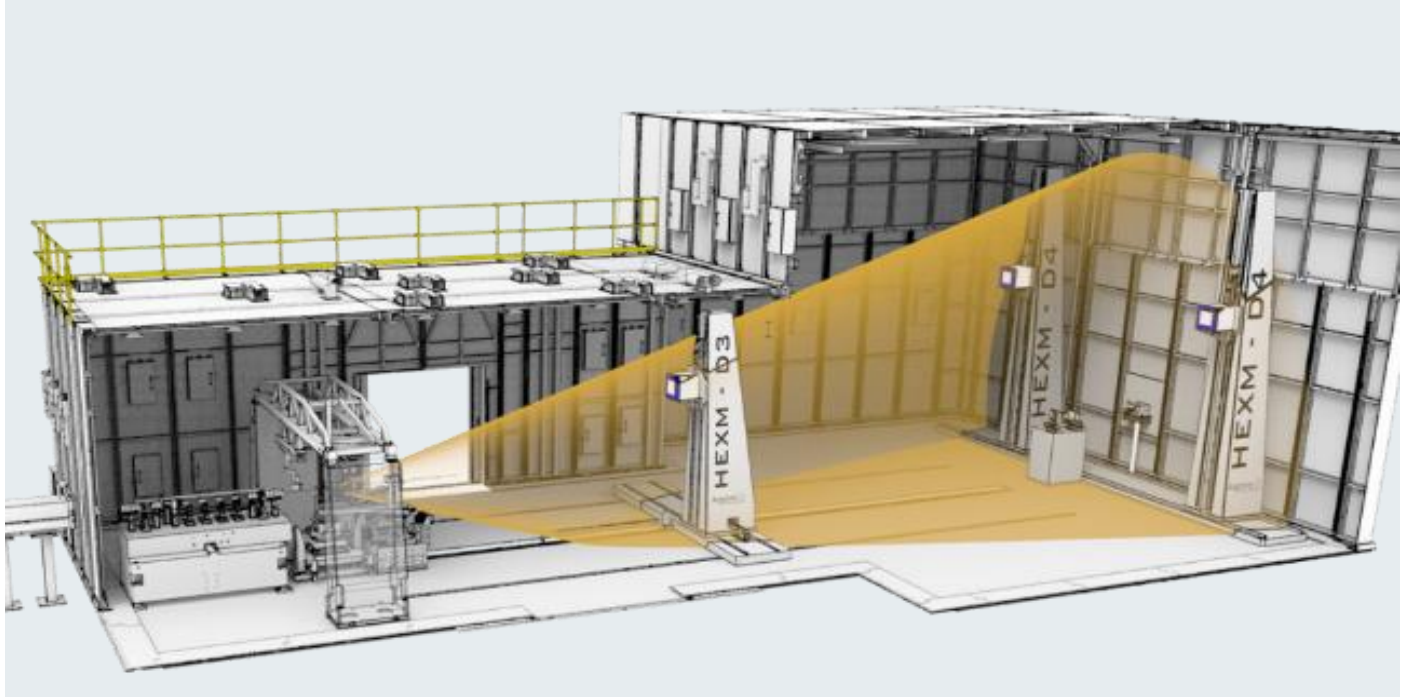
- Important to understand defects in fabrication processes
- Upgraded APS enables nondestructive probes of large volumes, at resolutions not attainable by optical methods
- Application: Microelectronics R&D prototyping phase and production ramp-up

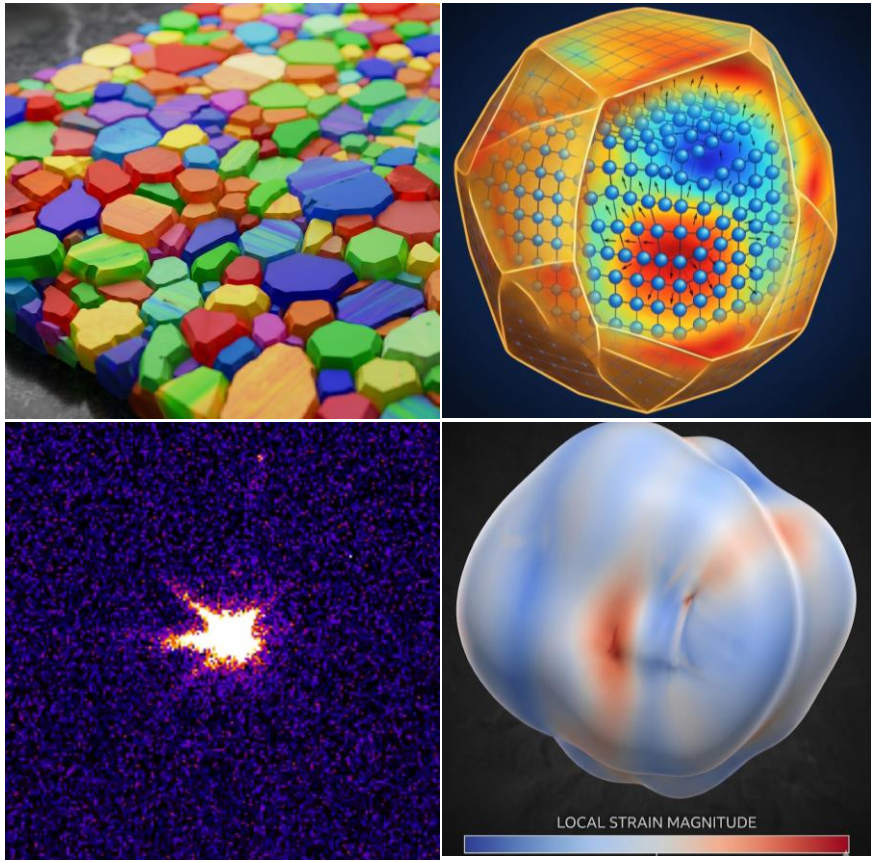


Nikitin et al., J. Synchrotron Radiation, 32, 1452-1462 (2025)

Understanding Engineering Materials (HEXM)

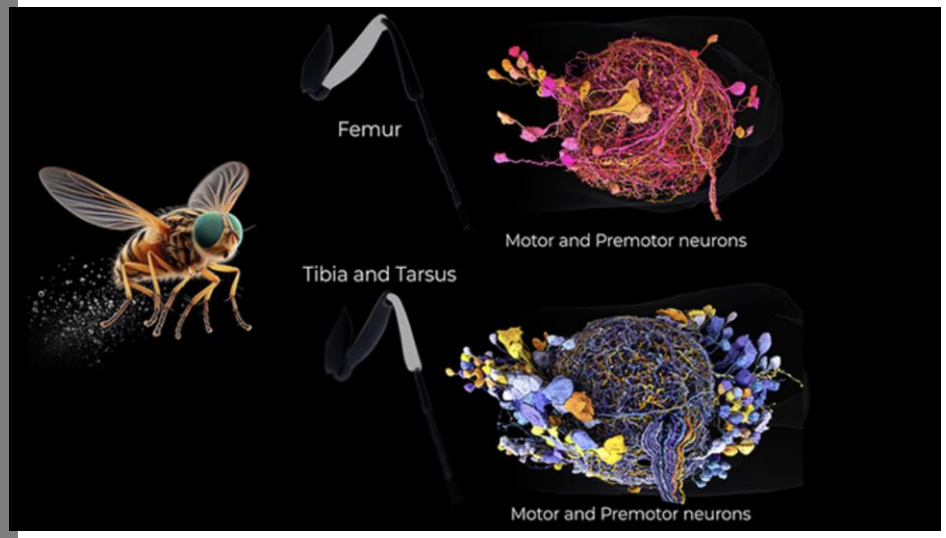
From mesoscale to strain at nanoscale





M. Angelone[1], M. Chlupsa[2], N. Porter[3], S. Oh[4], et al.
[1] Northwestern University, [2] University of Michigan, [3] BYU, [4] Argonne National Laboratory

(ESRF) ID16A: NANOIMAGING BEAMLINE FOR LIFE SCIENCES AND BIOMEDICAL RESEARCH

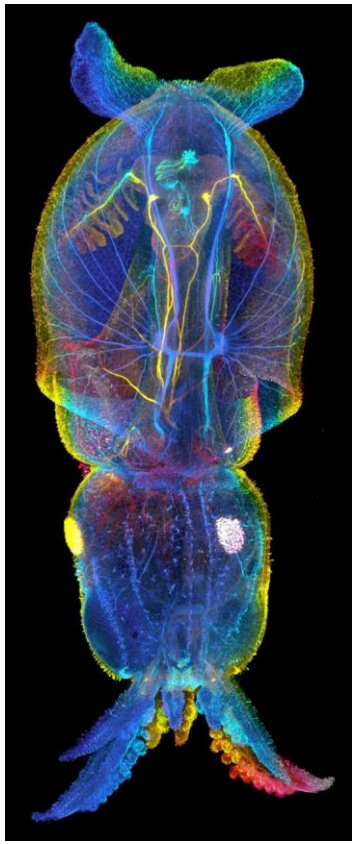


Neural networks controlling fly wing & leg movement

Azevedo et al. Nature 2024
Mamiya et al. Neuron 2023
U. Washington, Harvard Medical School

Structure-function mapping of mouse olfactory bulb circuits, combining functional and x-ray imaging.

Francis Crick Institute



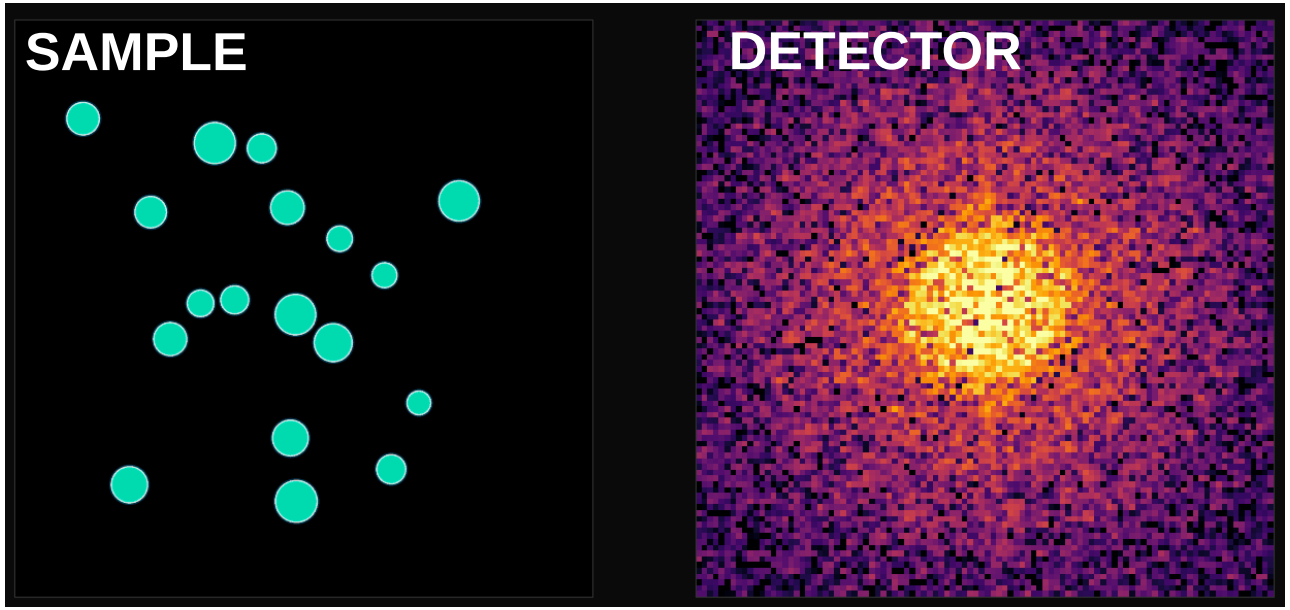
Complete neural wiring in a squid

Cardona Lab , MRC Cambridge

- **New technique, X-ray Nano-Holotomography, to advance nano-imaging for life sciences**
- ~30nm isotropic resolution across large tissue volumes, imaging neuronal circuits 100x faster than traditional methods.

Coherence enables probing of dynamics in complex systems

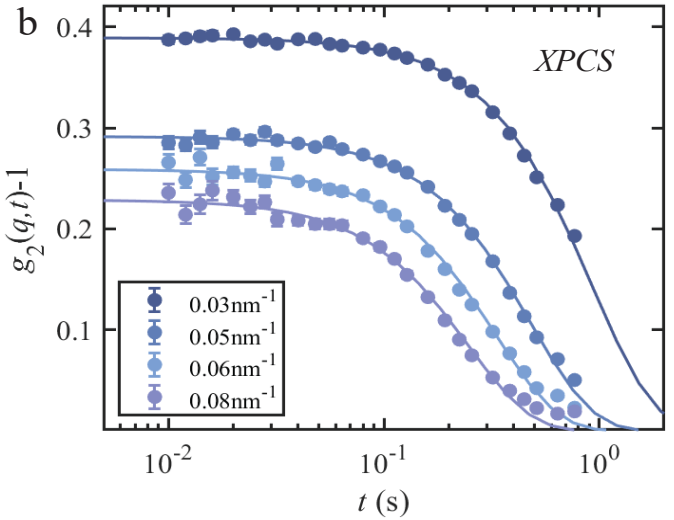
- Illuminating an object with coherent X-ray light produces “speckles” in the detector that encode information about disorder in the system
- Tracking how these speckles evolve as a function of time provides access to the dynamics of complex heterogeneous systems

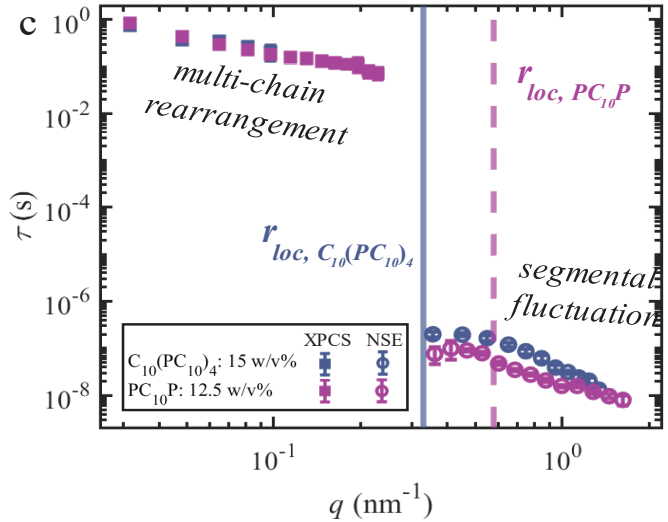


SMART materials

Coherent beam gives new insights into self-healing protein hydrogel

- Hydrogels have applications in tissue repairs, internal sutures, and soft robotics
- Beam coherence has helped understand dynamics of these complex assemblies
- Studying biological specimens with hydrogels was impossible at the original APS





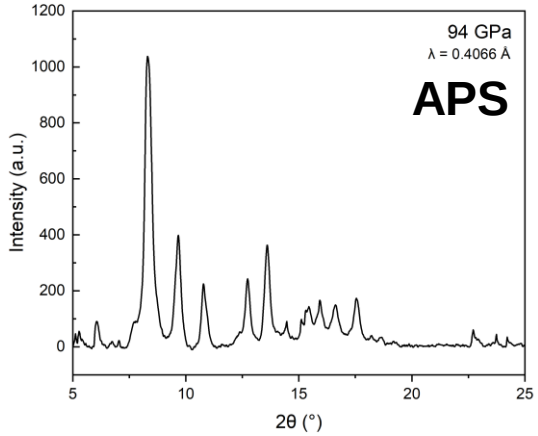
Work by B. Carrick, H. Yao, A. Rao, & B. Olsen of Massachusetts Institute of Technology, and Q. Zhang, M. Chu & S. Narayanan of the APS.
Team also used the Spallation Neutron Source at Oak Ridge National Laboratory in this research.

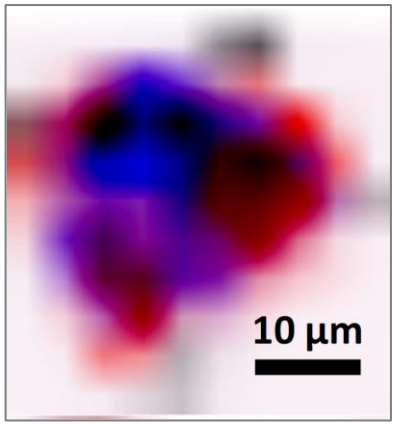
Material discovery

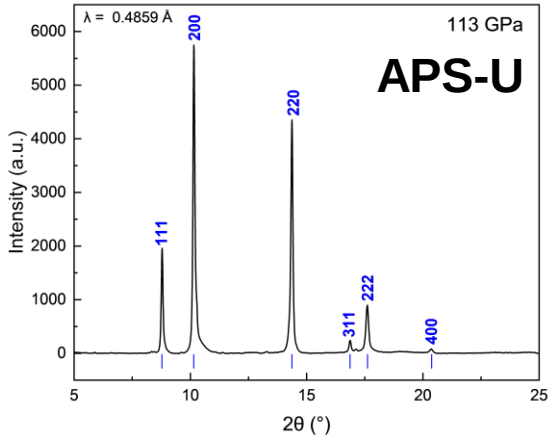
New superconducting phases

- Hydride superconductors can operate at high temperature under extreme pressure: Holy grail is to discover new phases that can be stabilized at room pressure
- Submicron X-ray beam opened the door to discovery of new phases in joint research with University of Illinois at Chicago

  [Manayil et al., *Nature Communications* **16**, 11222 (2025)]



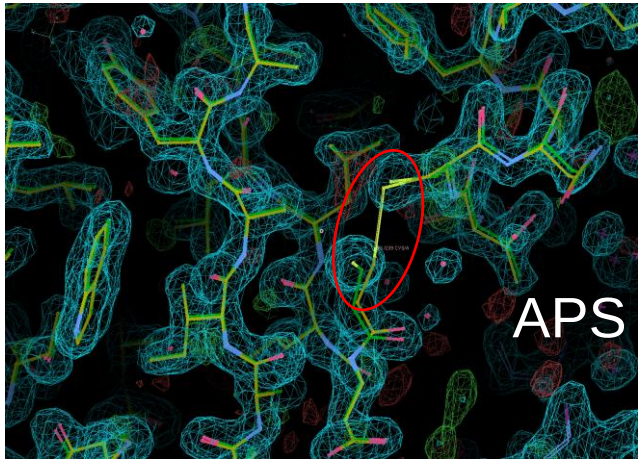


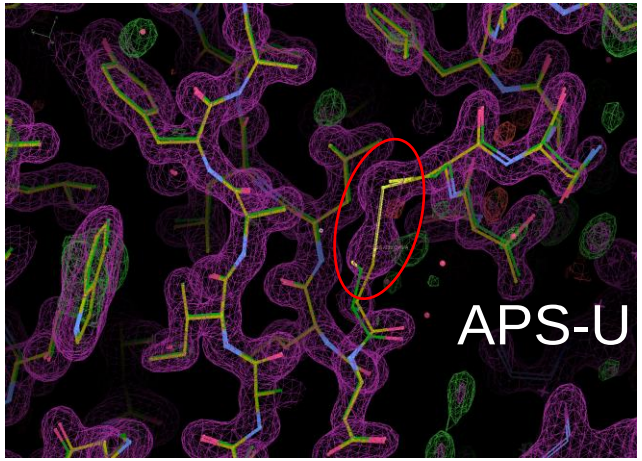


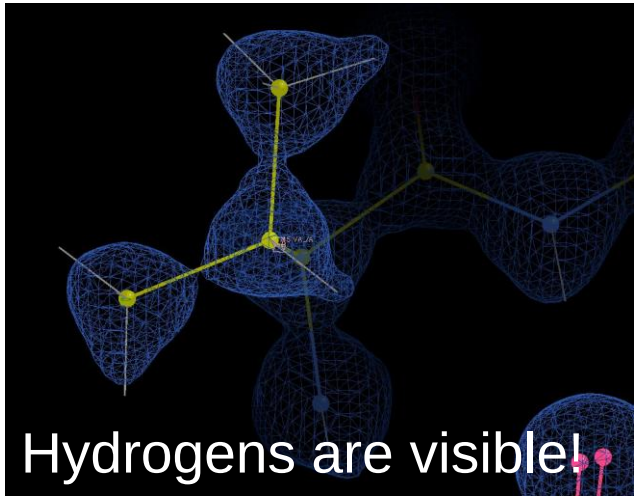
Protein structures

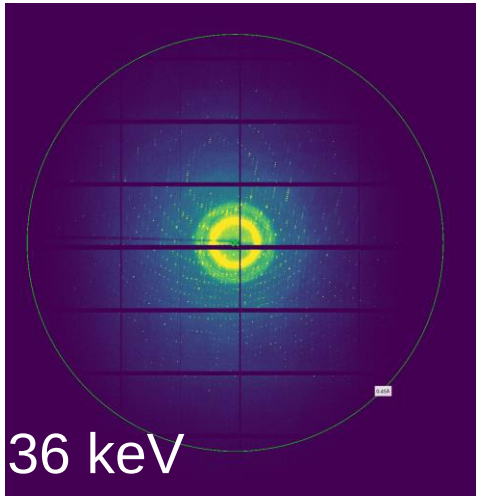
New modality and throughput for protein discovery

- Major speed-up in data collection
- The field is transitioning to serial crystallography, with partial data collected from multiple tiny crystals
- Approach gives better insights into protein behavior at room temperature
- Demonstrated entire pipeline that supports this modality at the upgraded APS
- High energy (20 -36keV and above)





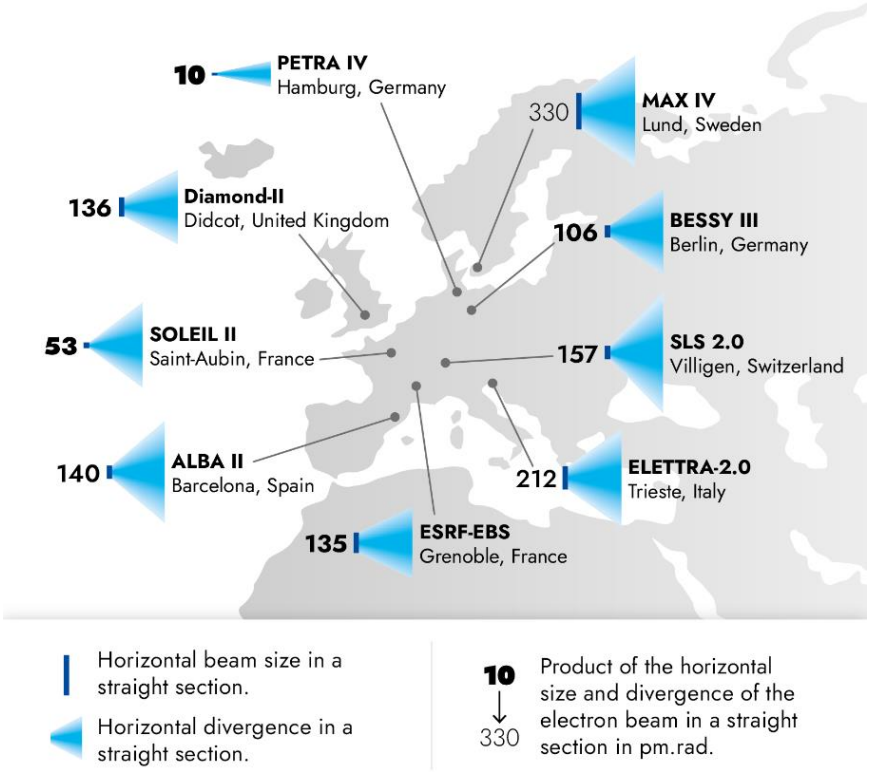


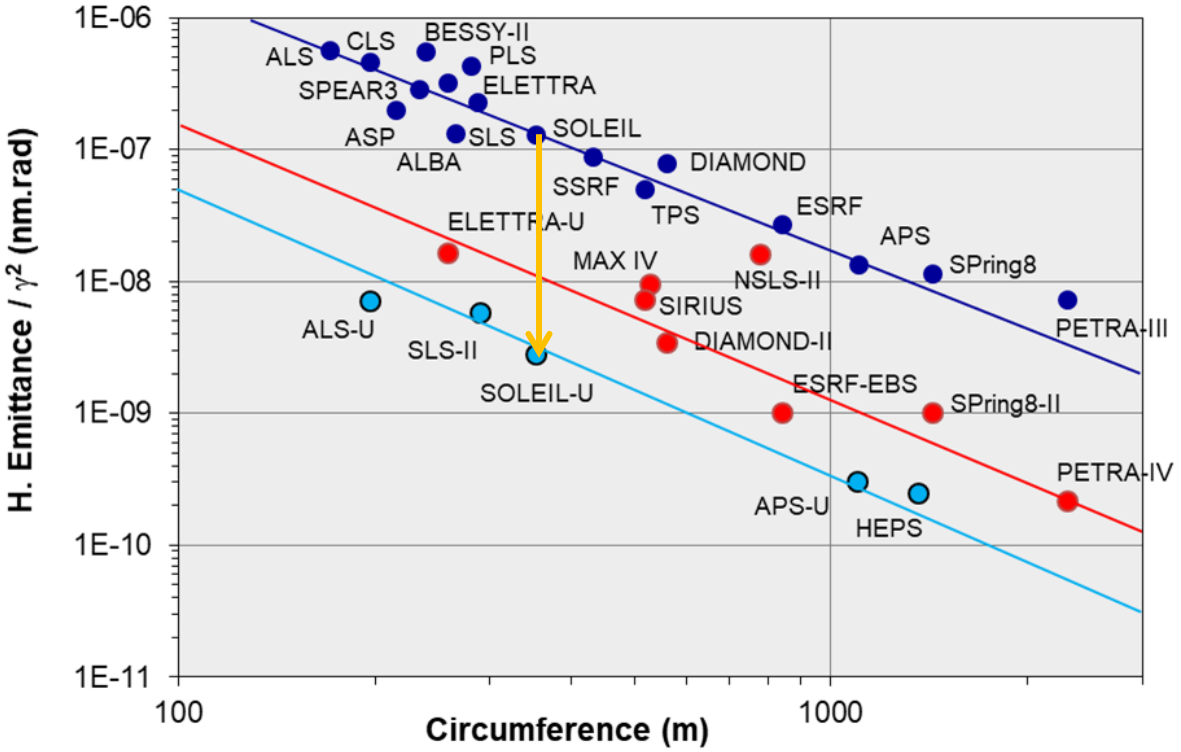


Work performed by SBC/eBERlight, GM/CA & NIH-sponsored NE-CAT teams

Recent and many upcoming upgrades

Adapted from J. Susini, Soleil



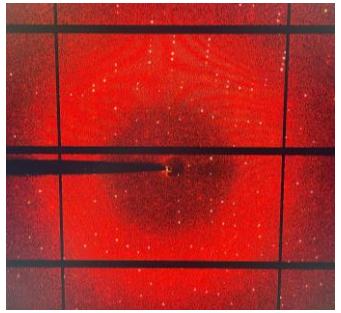


Susini, J. *et al.* A brief introduction to the Synchrotron SOLEIL and its upgrade programme. *Eur. Phys. J. Plus* 139, 80 (2024). https://doi.org/10.1140/epjp/s13360-024-04872-2

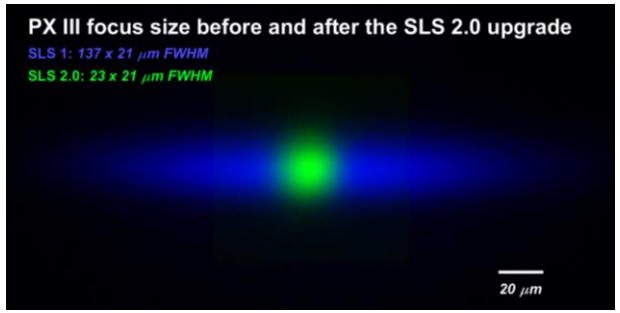
PX Beamline Upgrades @ SLS 2.0

PXIII

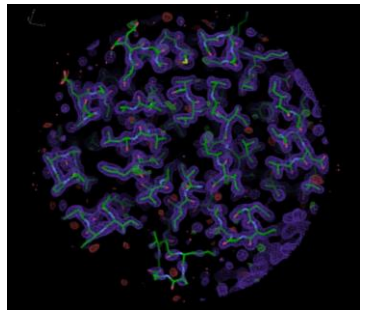
11 April
First Light (White Beam)



15 April
First Diffractions



12 May
Focused Beam



30 June
First Pilot-User
Fragment screening of alcohol dehydrogenase with Chem Space

AI

An AI-designed protein from Martin Pacesa (EPFL)

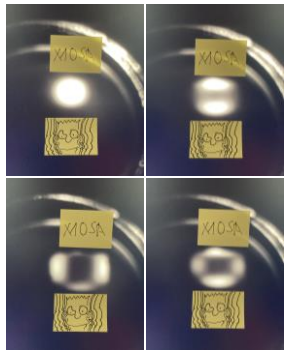
2025

September 25
First Light PXI

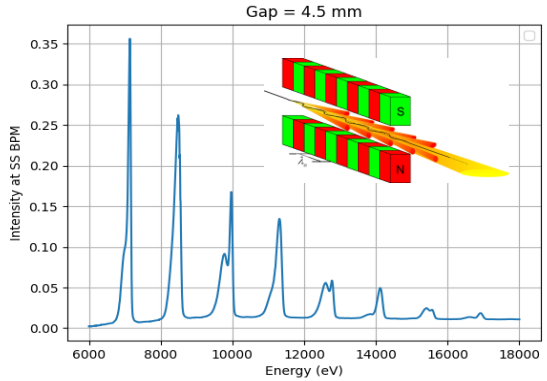
PXII

25 June
First Light (White Beam)

27 June
First Mono Beam



29 June
First Energy Scan



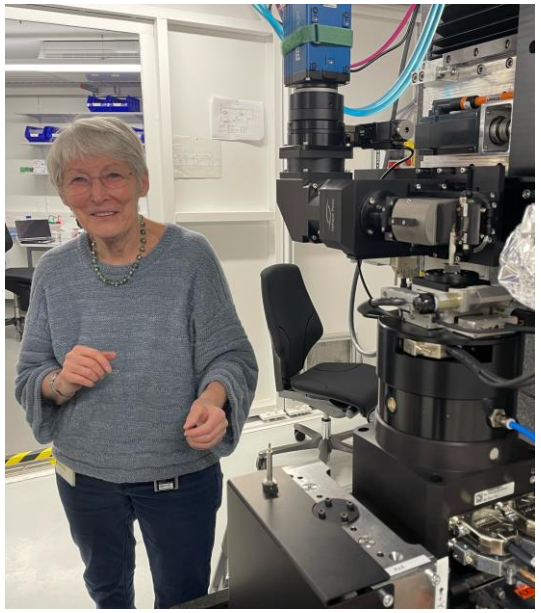
05 July
Focused beam at sample position

PXI

All optical elements so far investigated needed significant positional readjustments

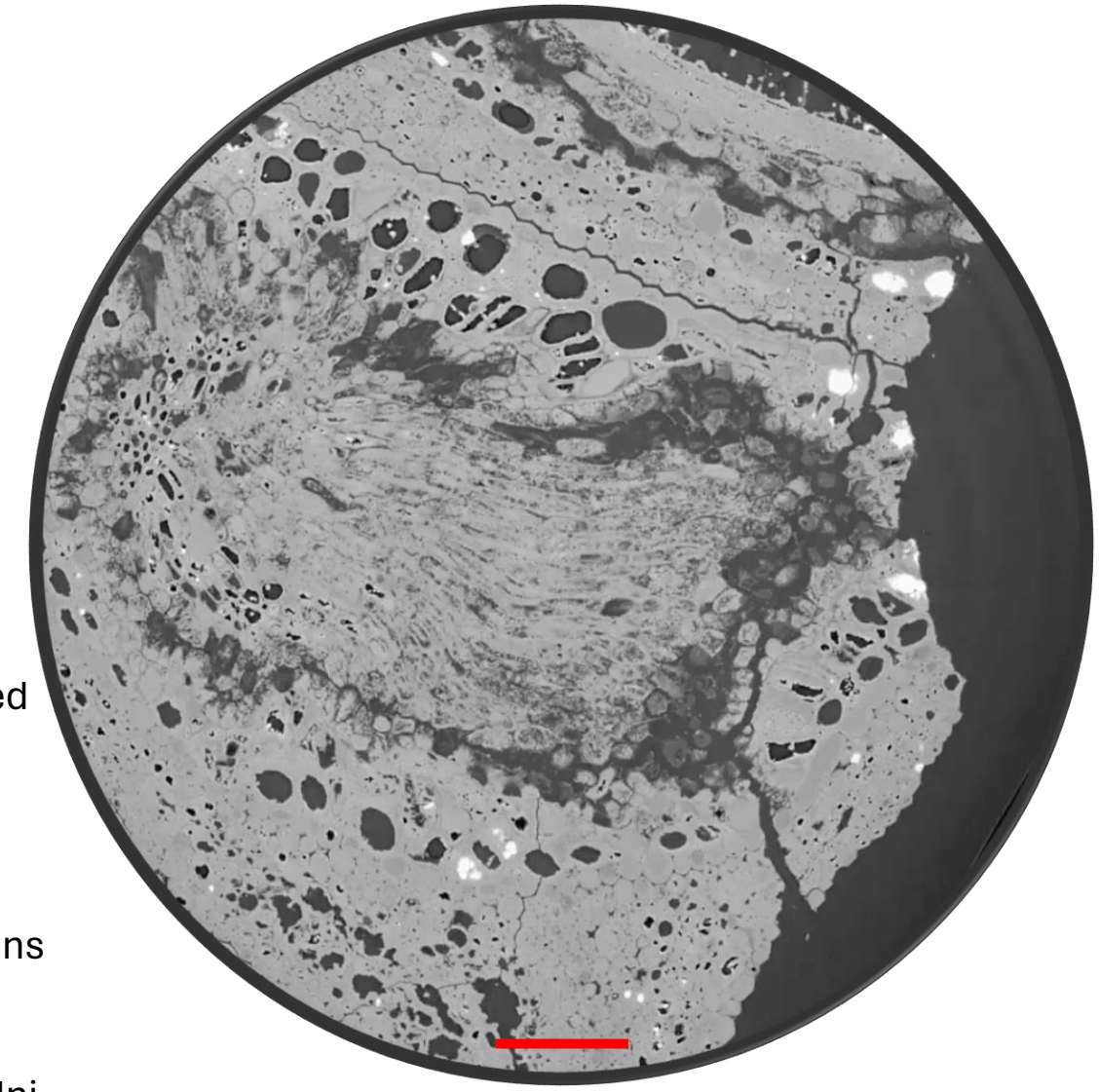
I-TOMCAT 2.0 @ SLS 2.0 First pilot experiment November 2025

- **Phase contrast tomographic scan at I-TOMCAT**
- Energy: 28 keV (13th harmonic U15)
- Field of view: 2 mm (H) x 1 mm(V)
- Pixel size: 480 nm (13 x mag)
- DAQ-scheme: 360° scan - 3000 projections
- Scan time: 5 minutes, 100 ms (with safety filter in)



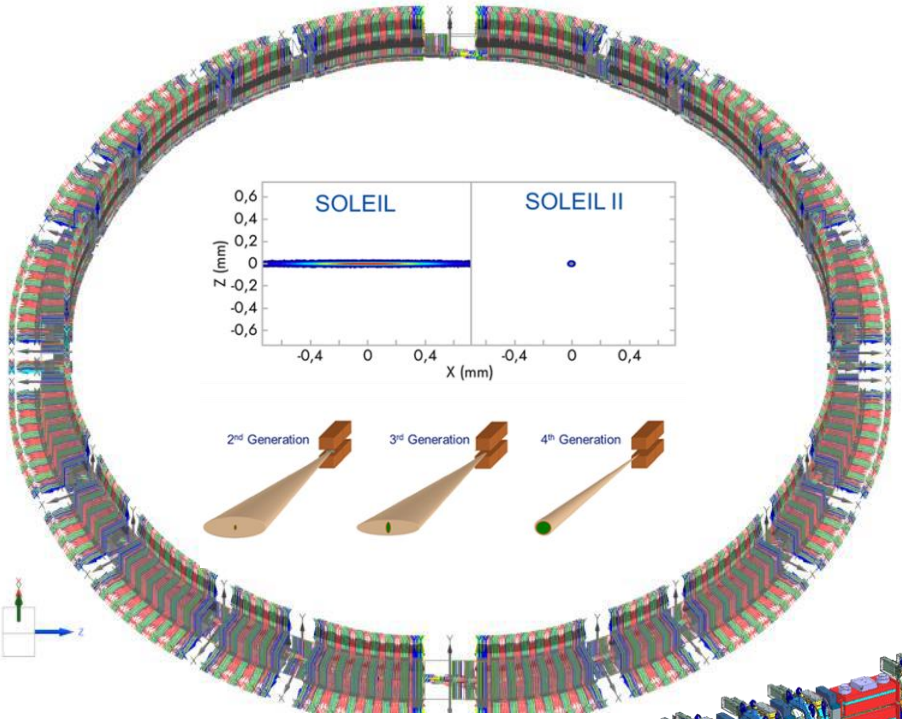
Sample: Cycadeoidea morierei (petrified Bennettites, extinct group of Mesozoic plants) from the Early Cretaceous of Normandy
One of the few fragment remains after specimen was destroyed in WW-II (Caens University)

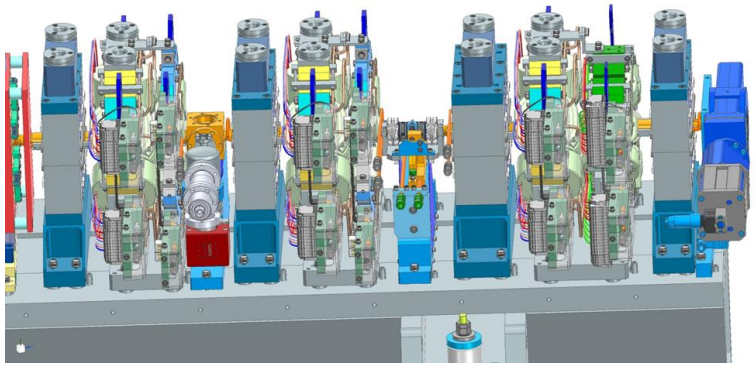
Principal investigator: Prof. E.M. Friis (Uni Aarhus)

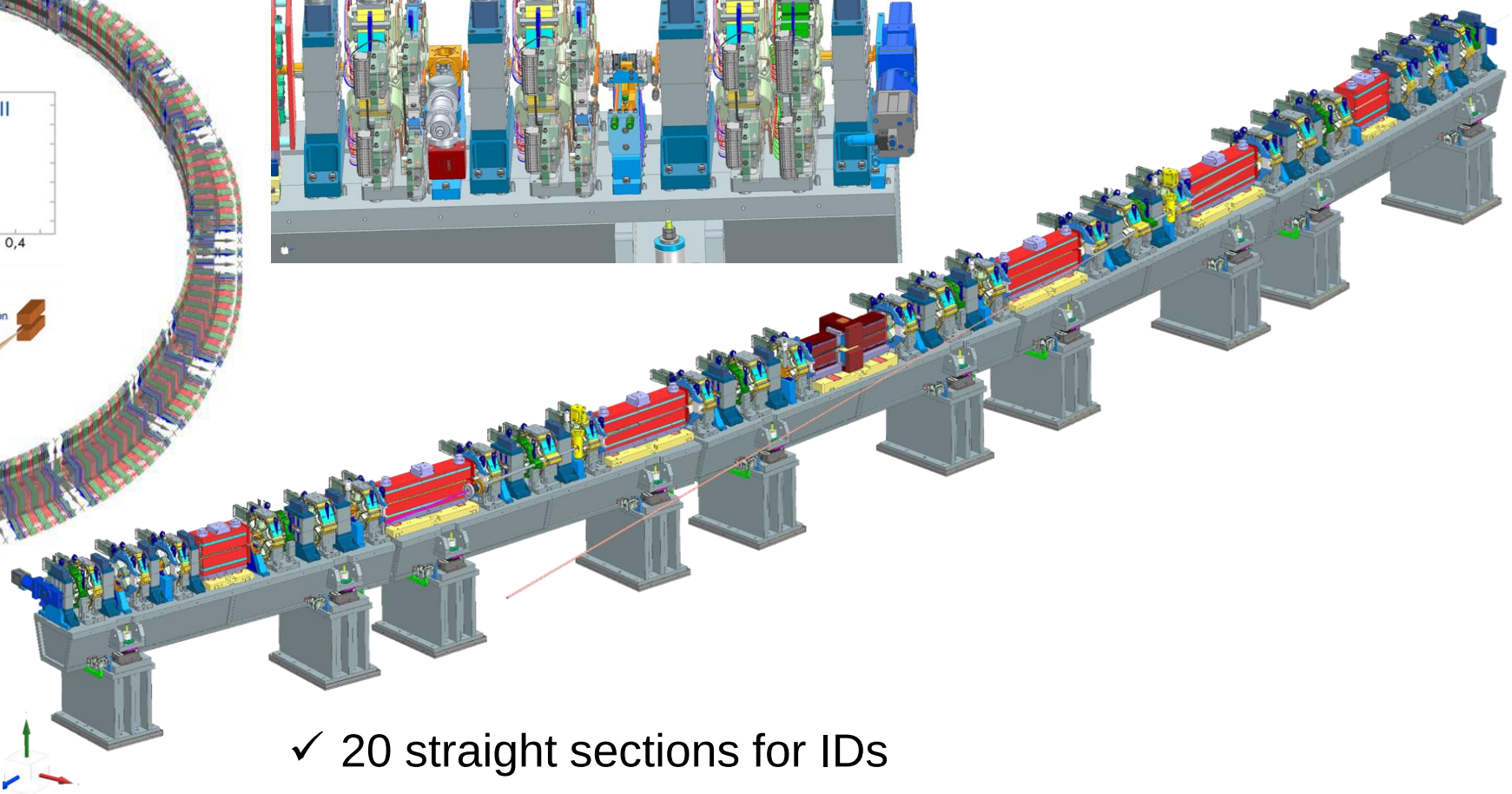


250 microns

The new storage ring - Soleil

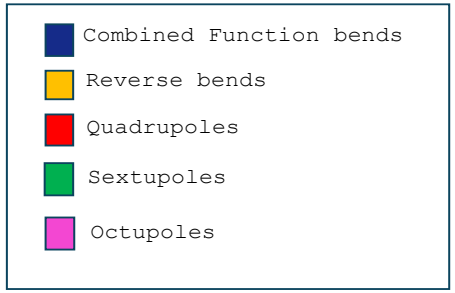




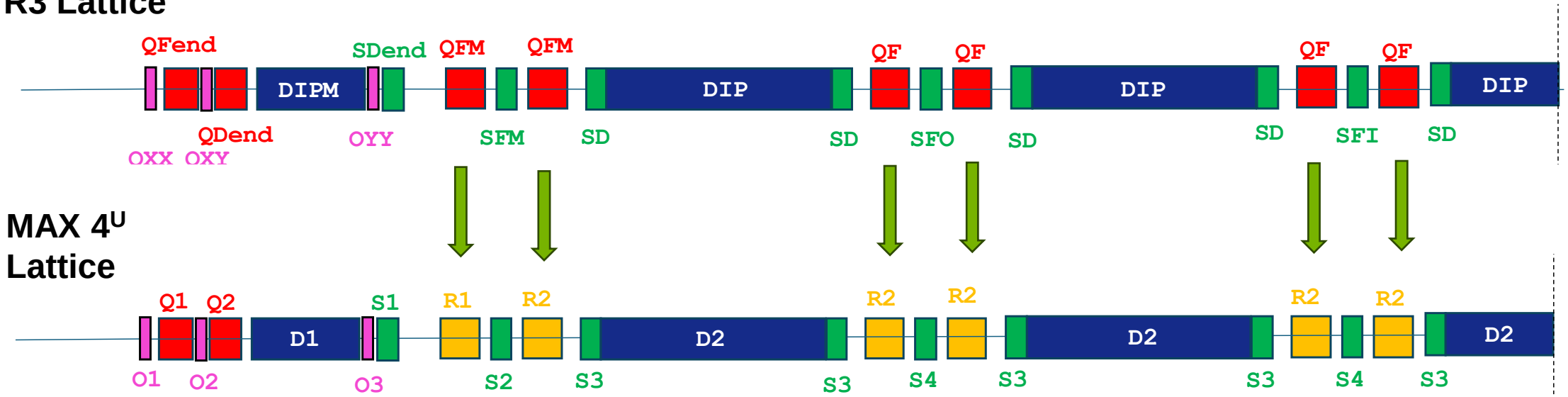


- ✓ 20 straight sections for IDs
- ✓ 8 « super-bends » (1,7 T et 3 T) at the middle of cell 7BA
- ✓ Several straight sections a bit longer

MAX 4^{U} Lattice



R3 Lattice



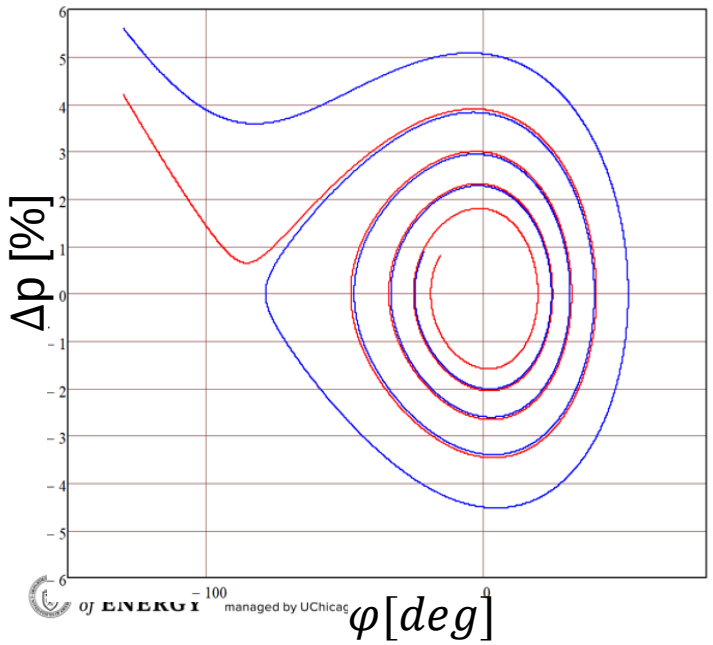
MAX 4^{U} Lattice

12 horizontally focussing quadrupoles are turned into reverse bends grouped into two families.

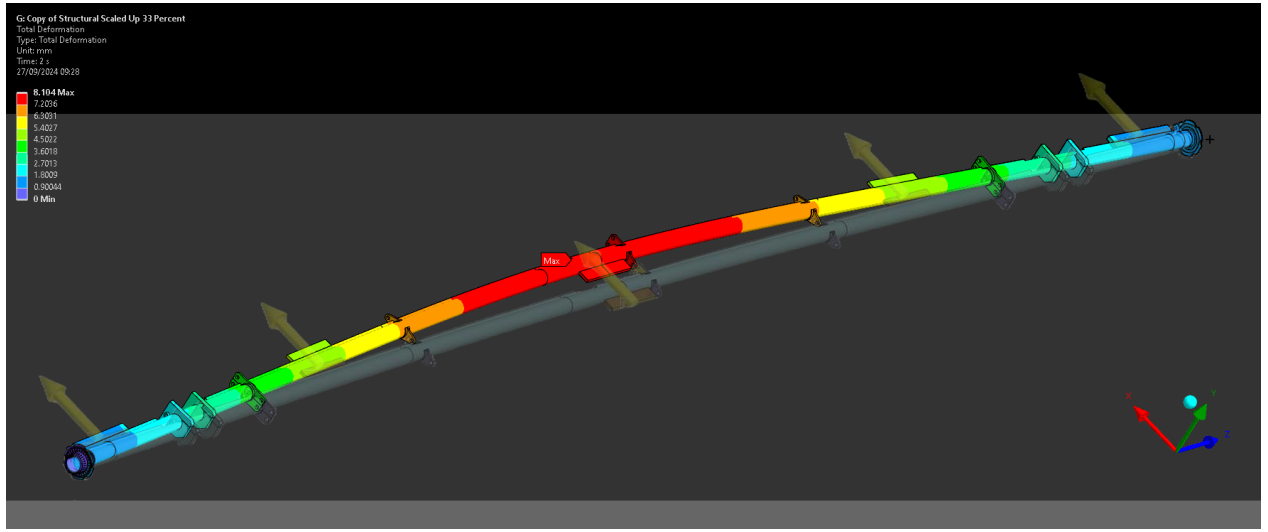
R3 = the existing MAX IV 3 GeV ring

MAX 4U Accelerator Design Highlights

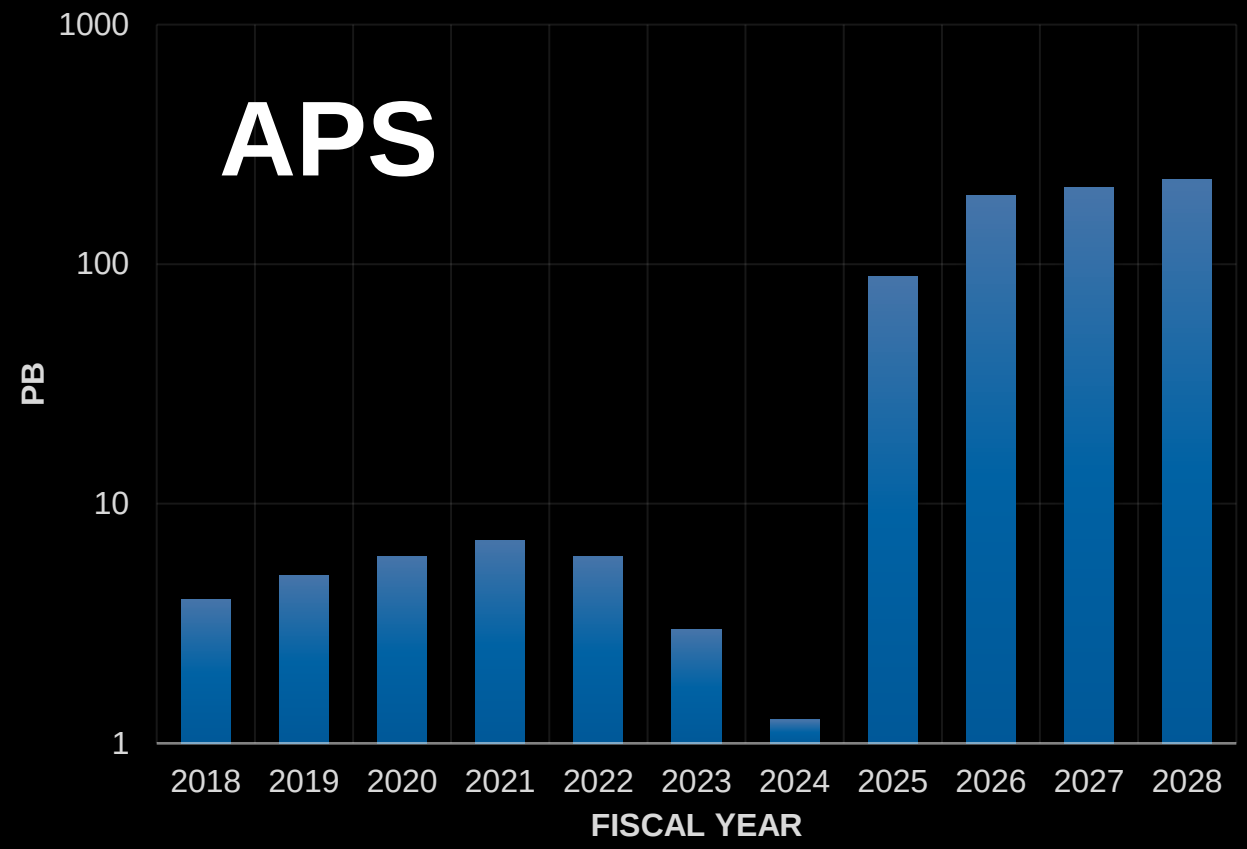
- **Off-phase Injection**
  - Injected beam comes with a time (phase) offset with respect to the already circulating electron bunches
  - Injected beam is kicked on-axis by a very fast kicker magnet. The stored beam is not perturbed



- **Re-use of vacuum chambers**
  - Chambers are bent into a new shape to follow the upgraded ring closed orbit.
  - Saves money and conditioning time



A Data Deluge



Volume

Velocity

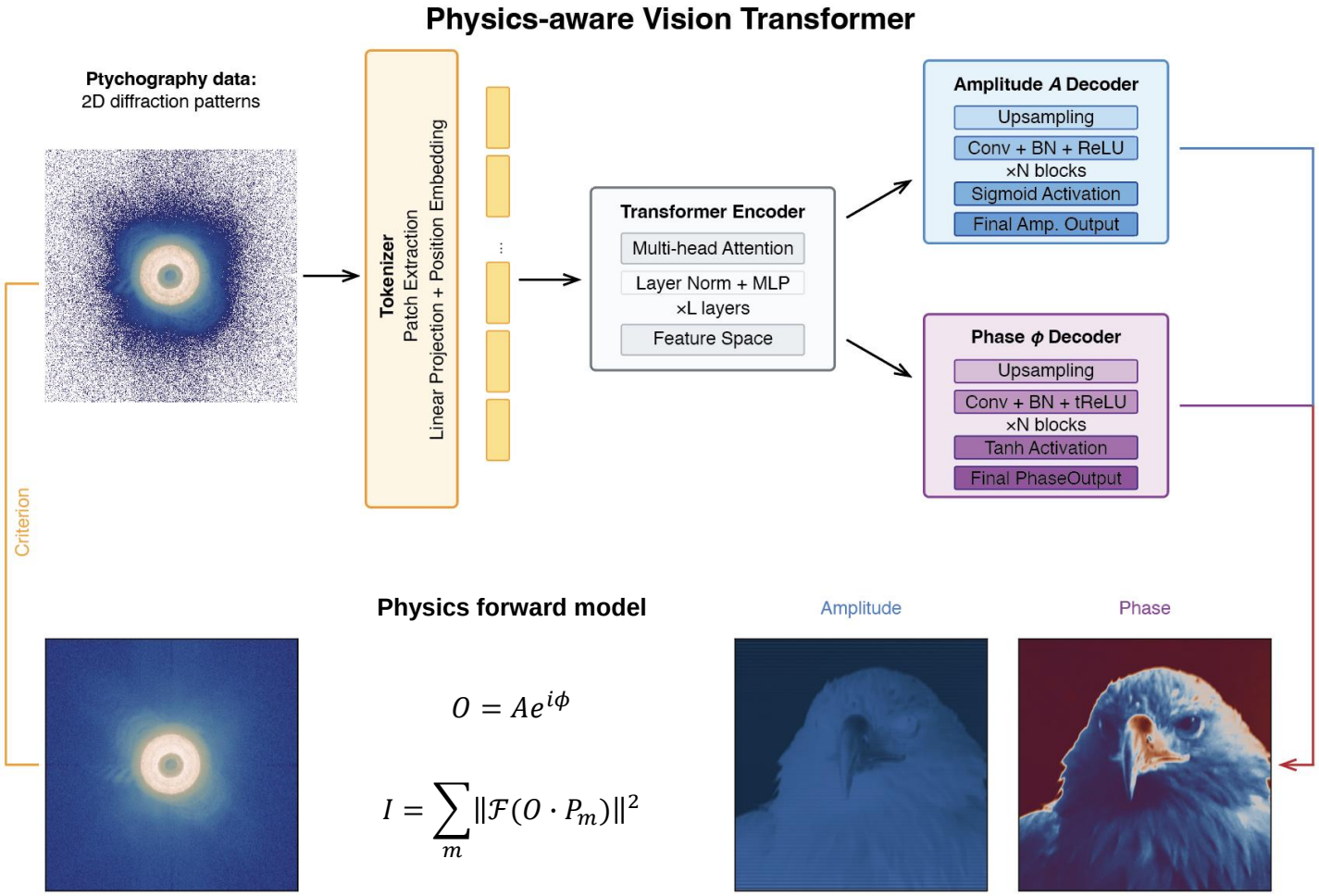
Variety

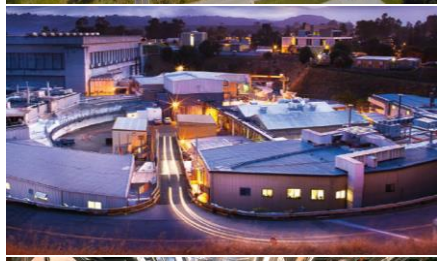
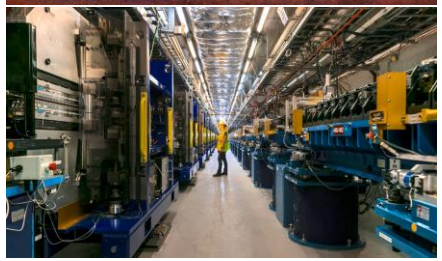
Veracity

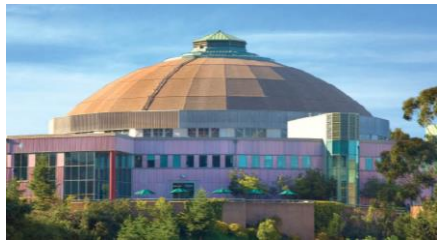
Value

Replacing conventional methods

Physics aware Vision Transformer (ViT)



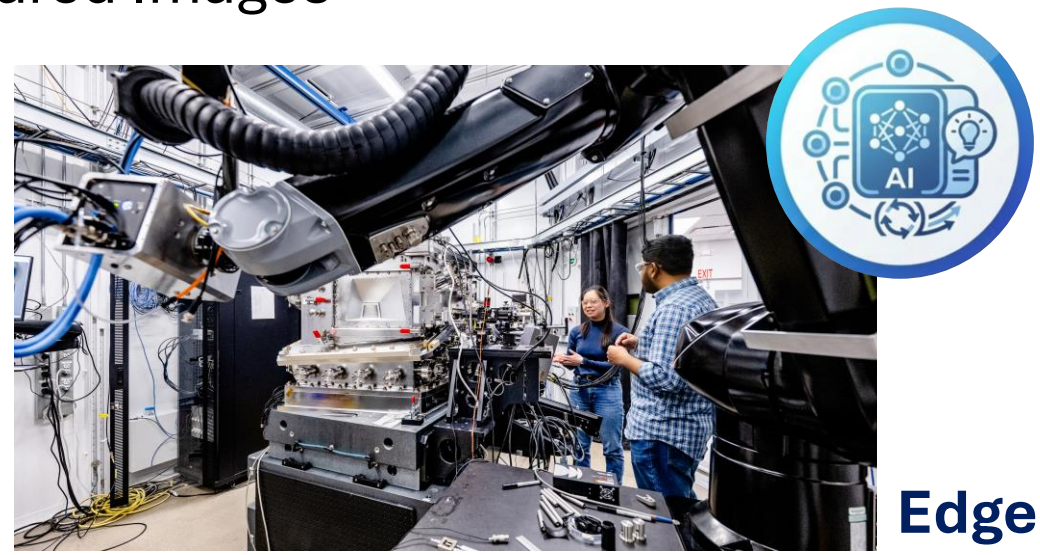


Genesis Mission

50 Million
Shared Images

Vision Transformer
Pre-Training
1024 A100 GPUs

Vision Transformer
Fine-Tuning
50K images
200 A100 GPUs

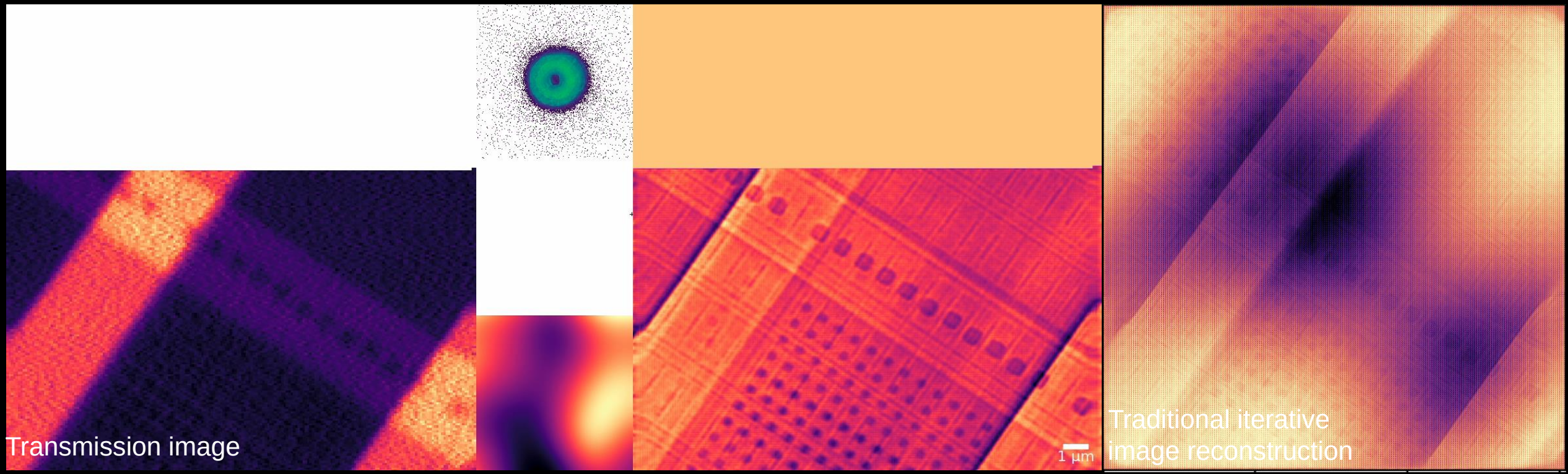


Edge-deployed

No AI

SYNAPSI PtychoFM

No AI



>10X Resolution
>>10X Contrast

>100X Faster

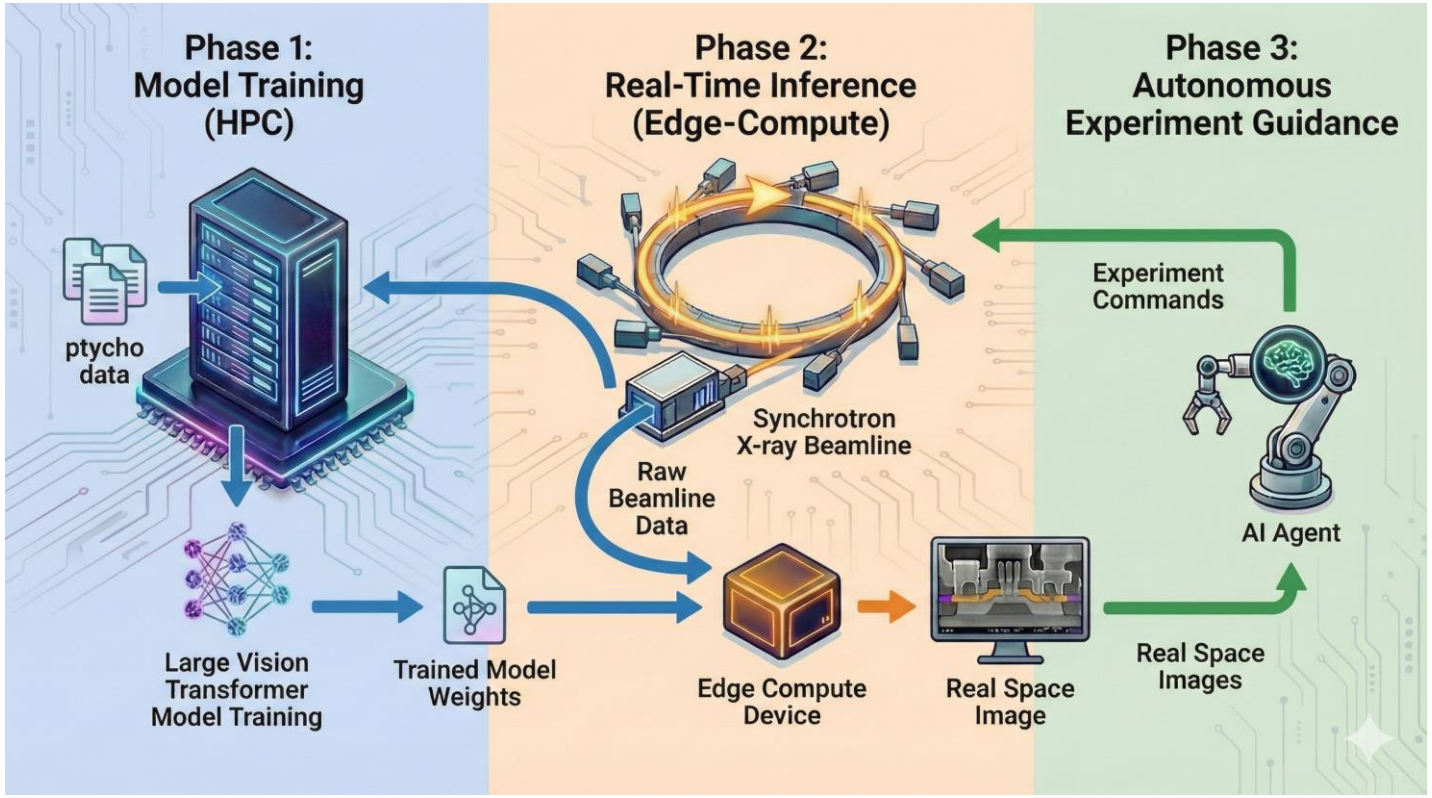
200 Hz live inference
Network Input: 256x256, Output: 256x256

Sample: 28 nm chip

Developing Agentic Beamlines

As part of the Genesis Mission

- We are developing foundational models for coherent imaging
- This will open the door for:
  - Real-time data analysis at the edge
  - Agentic beamlines: Autonomous agents to control and tune experiments



Du, M., Luo, Y., Banerjee, S., Wojcik, M., Popovic, J. and Cherukara, M.J.,. EAA: Automating materials characterization with vision language model agents. arXiv preprint arXiv:2602.15294. (2026)

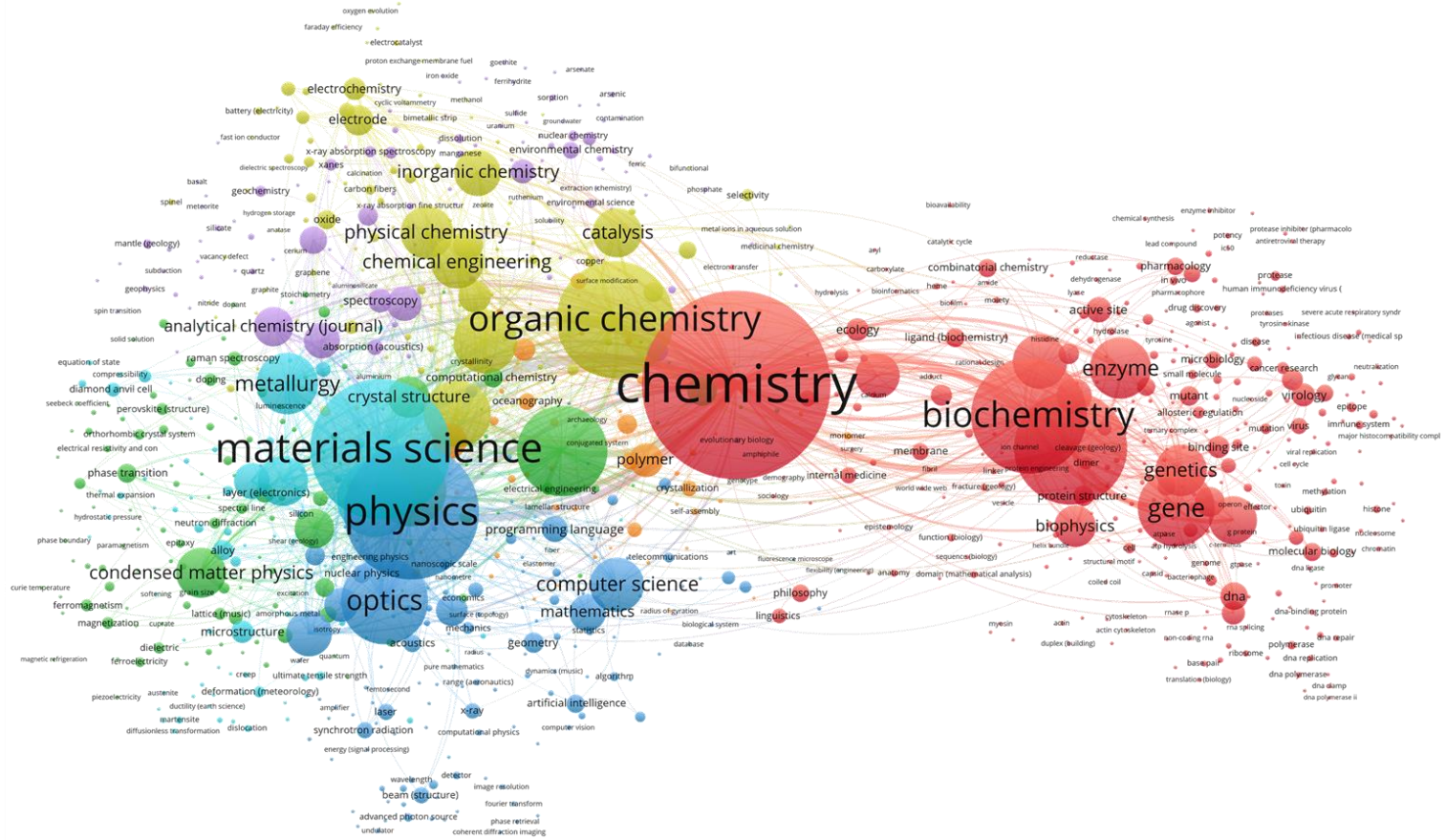
The future is bright !

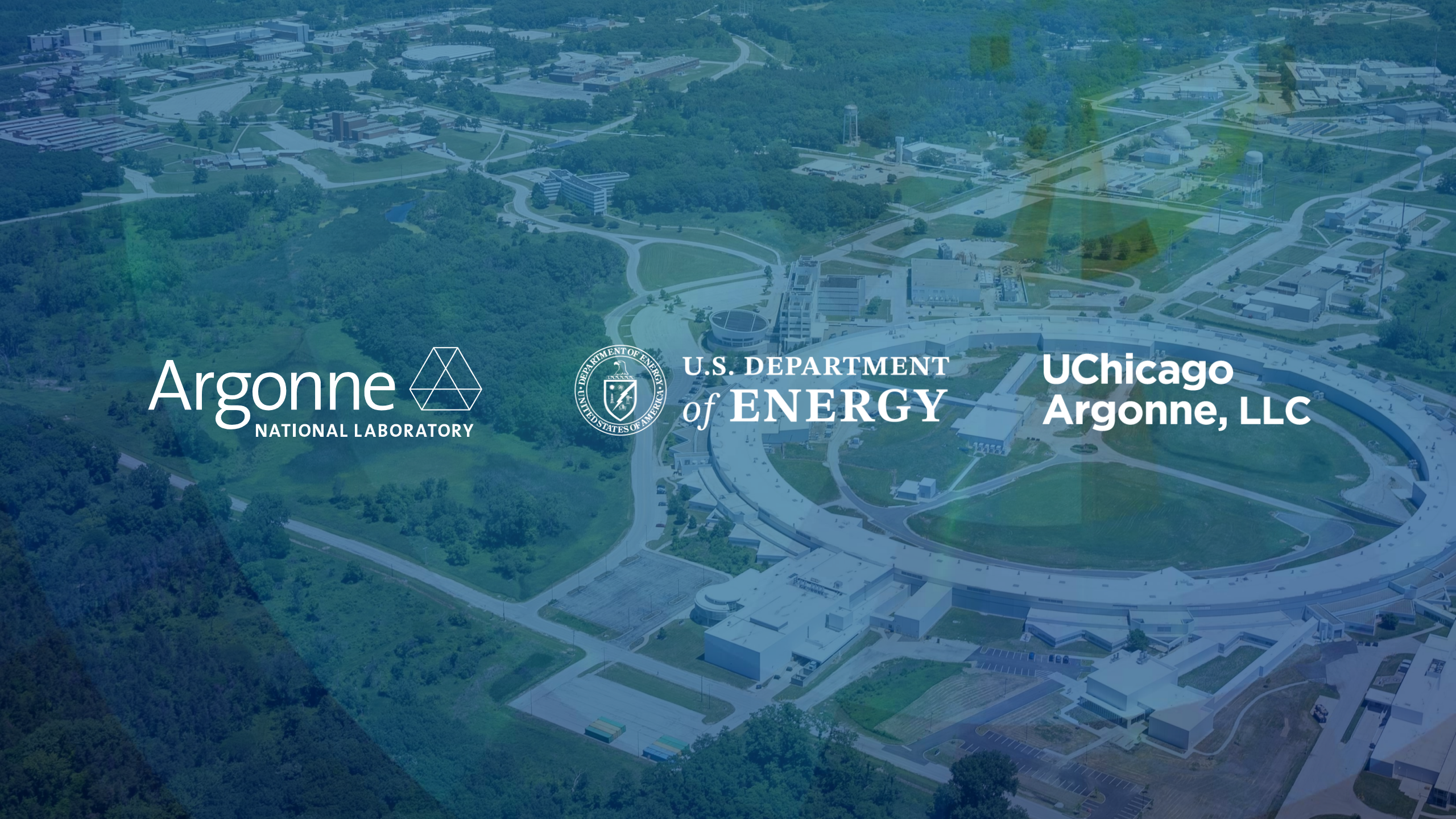
APS impact 1996-2023

36,226
publications

2.2 MILLION
citations

33,110
patents

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