EPICS SUMMER SCHOOL

Science with Synchrotrons:

How synchrotron facilities explore the world and why control systems make it possible

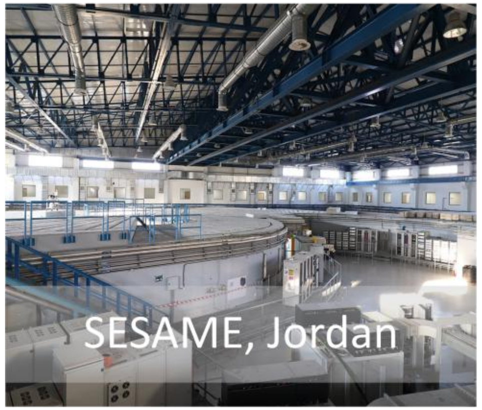
Mirjam Lindberg, MAX IV Technical Director

This is MAX IV

- A Swedish, national laboratory for X-ray research with Lund University as host
- First fourth-generation light source – up to 100 times brighter than the earlier generation and highly coherent
- In operation since 2016
- Available for academic and industrial users worldwide

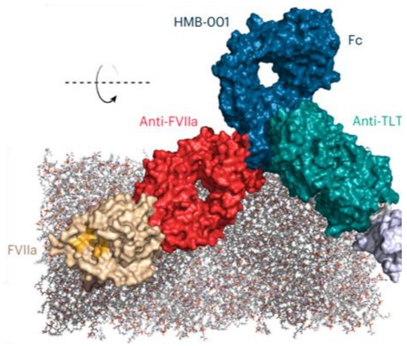
MAX IV

Synchrotron facilities around the world



The brightest X-rays in the world

Health

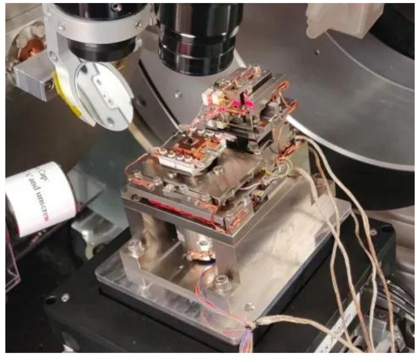


Designing new medicines

Clean Energy

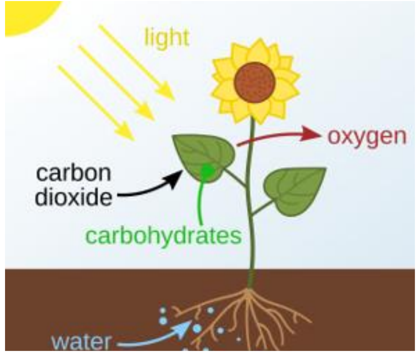
Flexible solar cells

Future Tech



Building better electronics

Climate



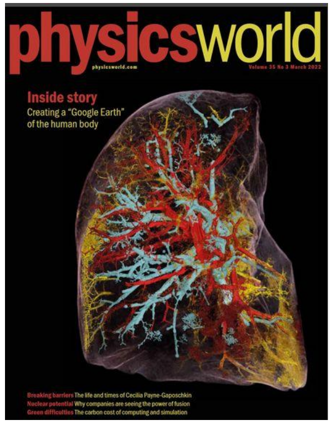
Artificial photo-synthesis

Making the invisible visible

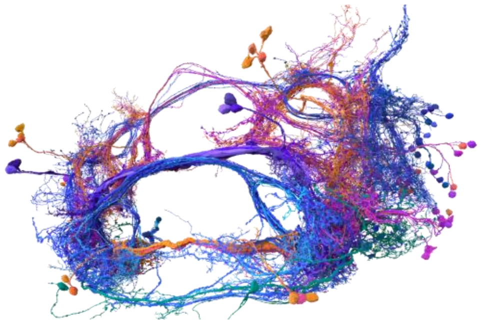
Properties of 4th generation synchrotron light

X-ray brightness

Imaging macroscopic objects with 10s of nanometer resolution – **more photons in a smaller beam**



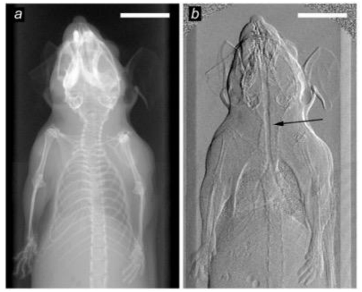
Human organ atlas



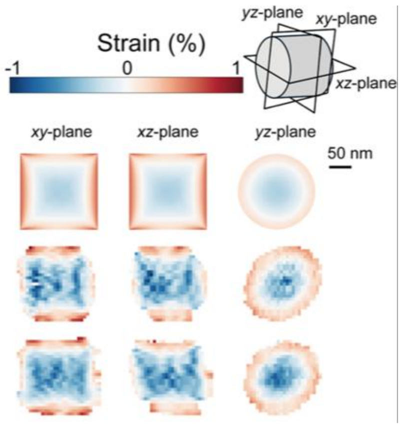
Flywire

X-ray coherence

Understanding disordered matter with the **highest spatial and time resolution**



Phase contrast (full field) – faster collection, lower dose

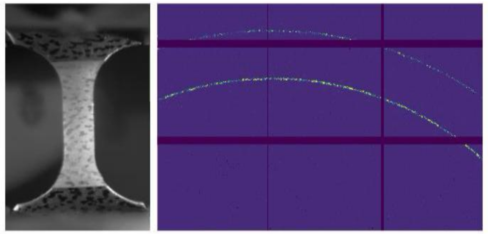


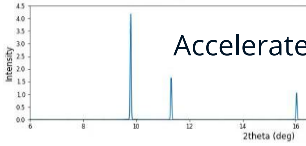
Strain in nanostructures and semiconductors

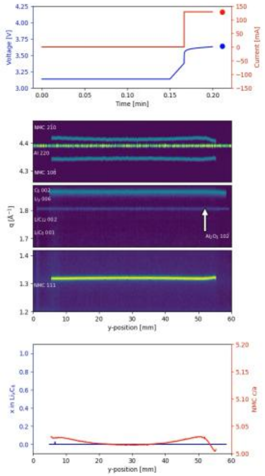
Energy resolution

Probing properties of real matter in-situ and operando with **higher energy resolution**

$\lambda \approx 10^{-9} – 10^{-10}$ m

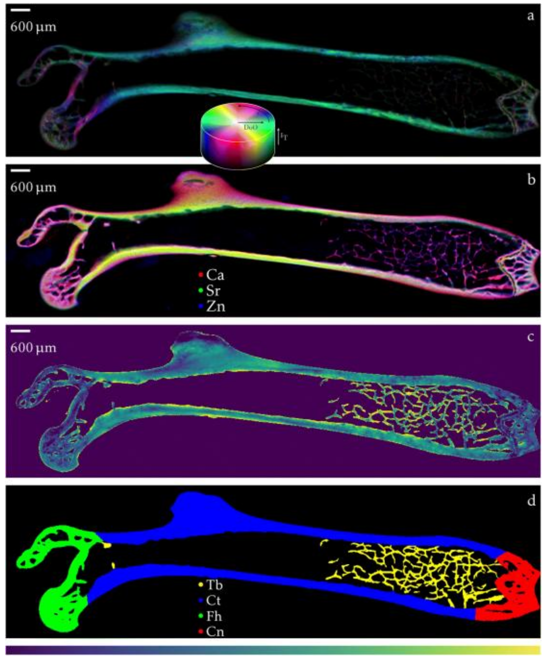


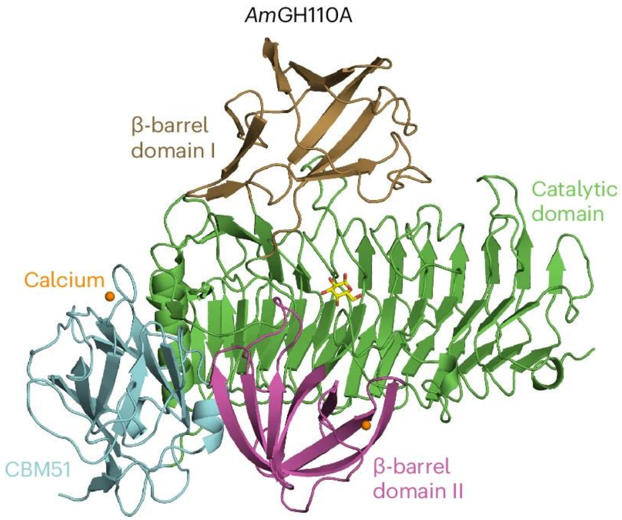


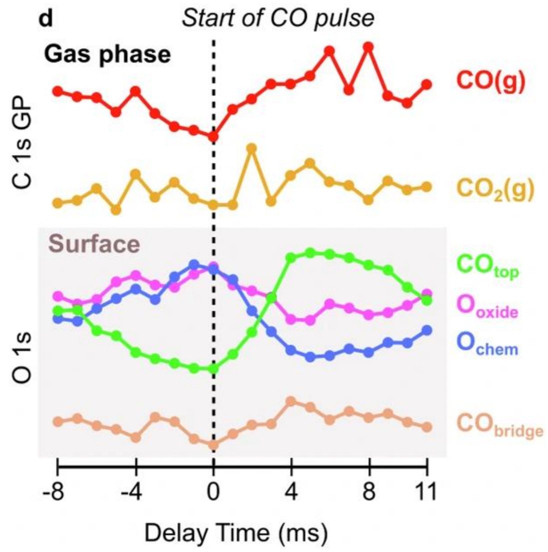


Battery-charging

Experimental methods







Imaging

Displaying structural and electronic details with nanometric resolutions in 2 and 3 dimensions.

Scattering and diffraction

Understanding the 3D structure of materials with resolutions down to atomic details.

Spectroscopy

Understanding the electronic structure and chemical state of materials.

Figures

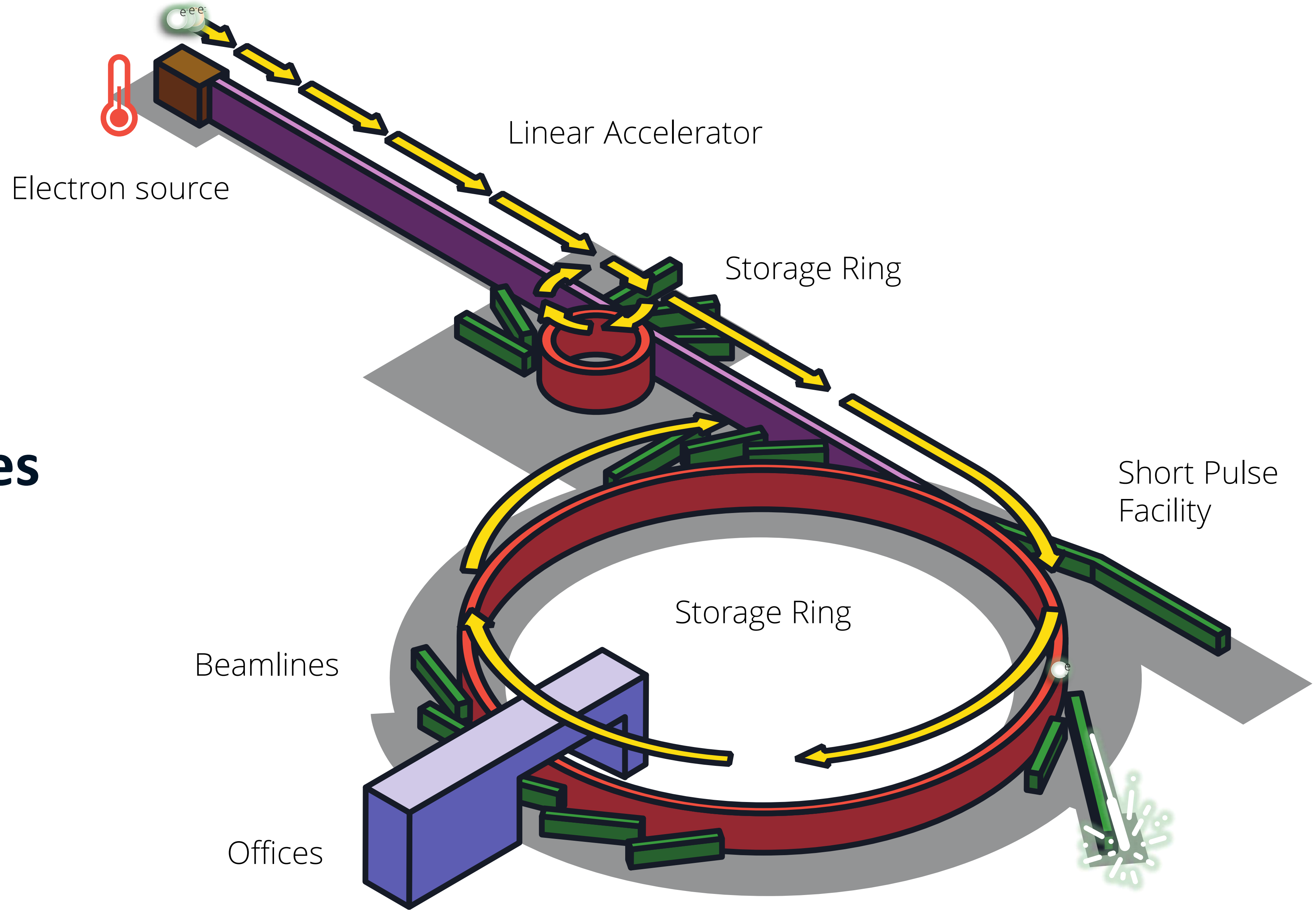
T. E. K. Christensen et al., Faraday Discuss., 2025, Advance Article

M. Jensen et al., Nat Microbiol 9, 1176 (2025)

C. N. Eads et al., Nat Commun 16, 1216 (2025)

Animation by: Gürhan Yana, MAX IV

A synchrotron – the basic features



MAX IV overview

3 accelerators:

- 3 GeV injector Linac with SPF
- 1.5 GeV storage ring
- 3 GeV storage ring
- 4 diagnostic beamlines

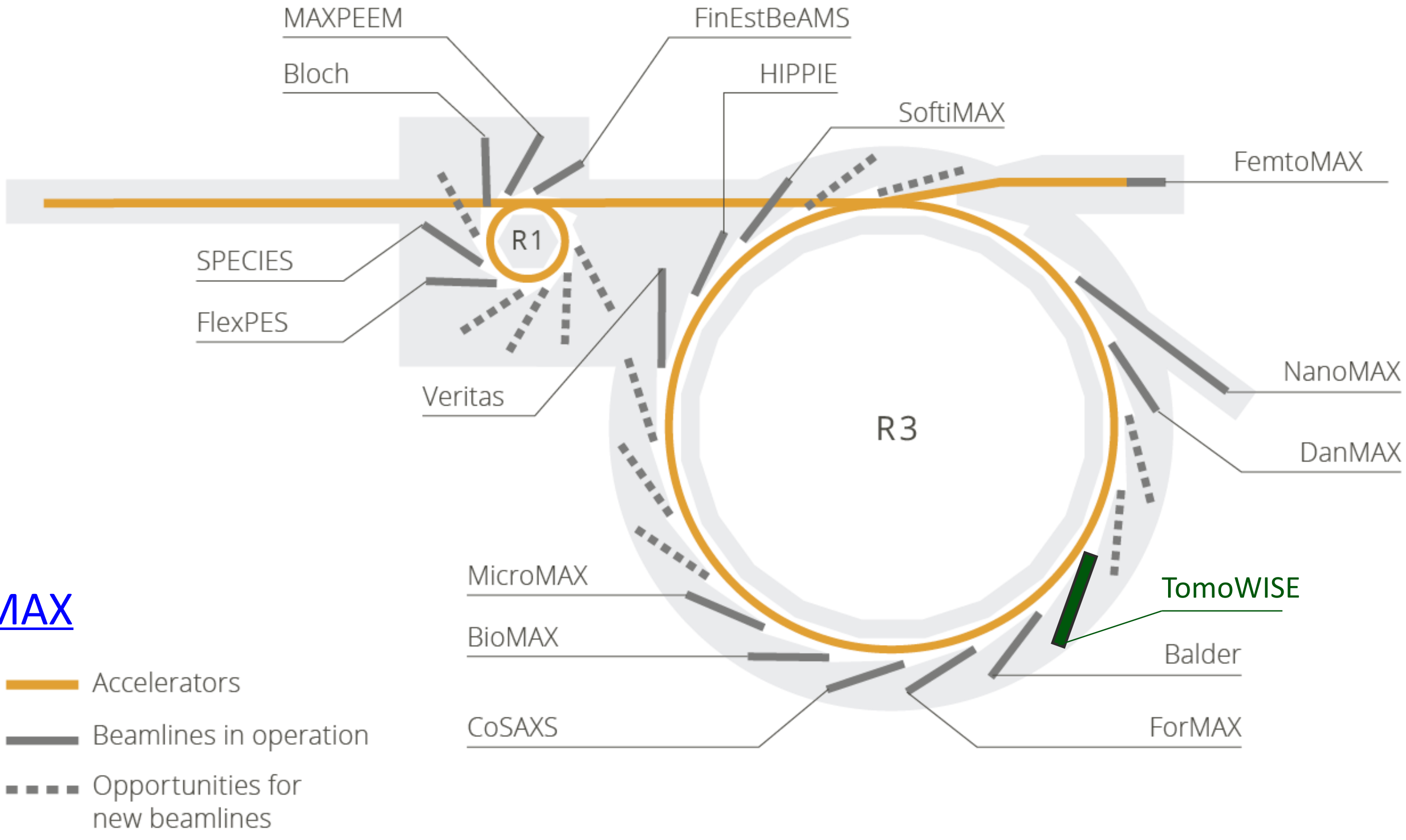
16 beamlines in operation:

- 24 branches
- 1 branch in construction – SinCrys at DanMAX

1 beamline in construction:

- TomoWISE – founded by WISE
- Full-field tomography, 20 to 65 keV
- $>10^{12}$ ph/s and and 45 mm x 4.5 mm beam

10 support labs and/or systems



2025:
2078 visiting users
97,8 % accelerator uptime

MAX IV

A user journey: from question to dataset

A successful experiment depends on much more than the X-ray beam.

Idea → Proposal → Preparation → Experiment → Dataset → Publication

> *Beamtime is precious — every hour concentrates years of preparation.*

The parts that make up a synchrotron

The user sees an experiment station — the facility is a layered system.

Accelerator systems	Generate and maintain the electron beam
Beamlines	Shape, condition & deliver the X-rays
Experimental stations	Position samples & collect data
Controls, computing & operations	Connect everything together

> *The experiment is the visible tip of a much larger technical iceberg.*

The hidden machine behind the experiment

> *The experiment succeeds only when the whole ecosystem works together.*

- Magnets, power supplies, vacuum systems & diagnostics
- Motors, shutters, optics, detectors & sample environments
- Networks, databases, software services & user interfaces
- Operators, support teams & scientists working in parallel

Why do control systems exist?

They let a facility observe, coordinate, protect and automate itself.

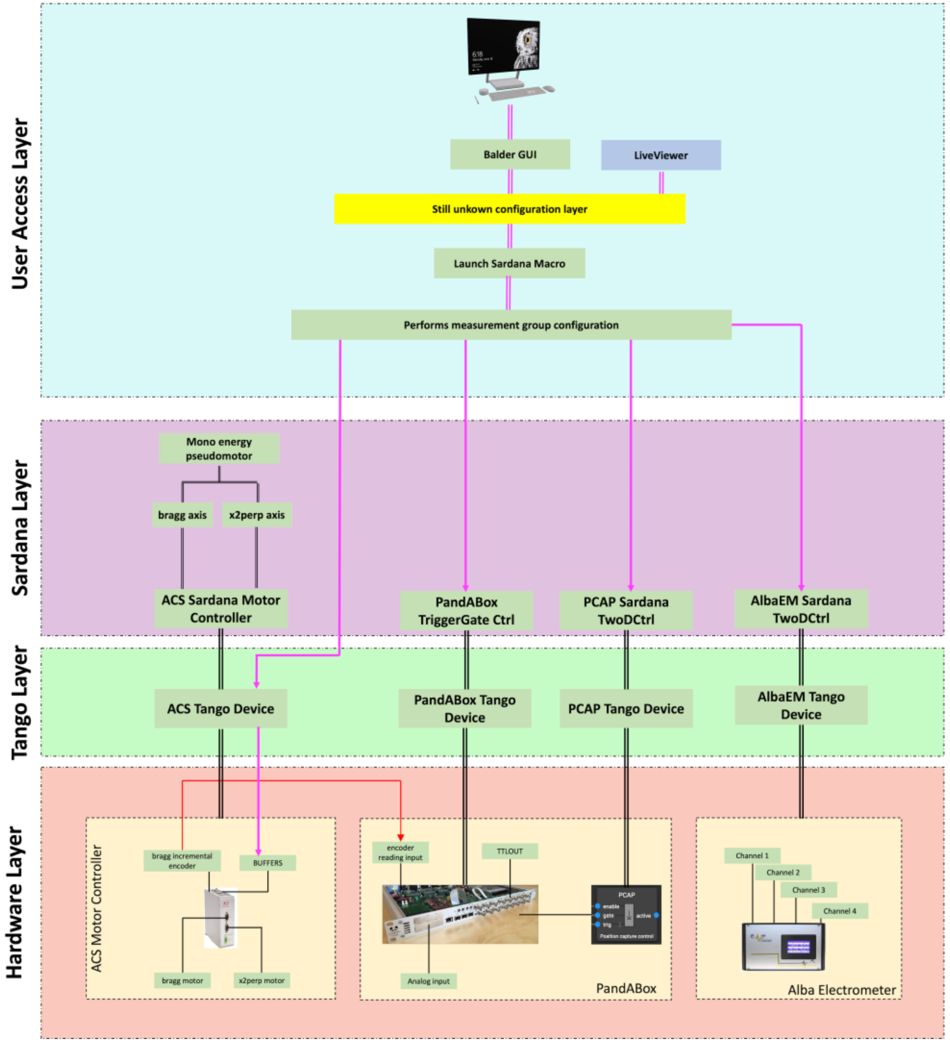
Monitor — See what is happening across the facility

Control — Send commands to equipment & services

Support — Serve operators and scientists through automated workflows

Record — Trigger data acquisition and log actions and parameters

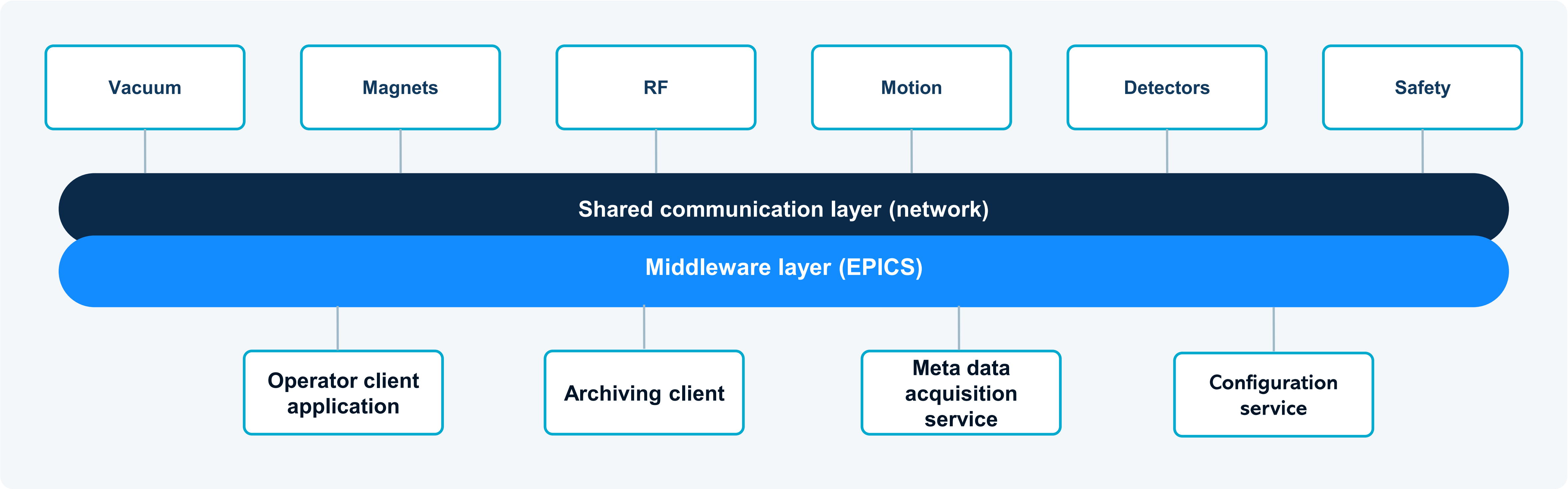
> *The control system is the nervous system of the synchrotron.*



CONTROL SYSTEMS LIKE EPICS AND TANGO

Why do we need distributed control systems?

A synchrotron is too large and specialised for a single central controller.



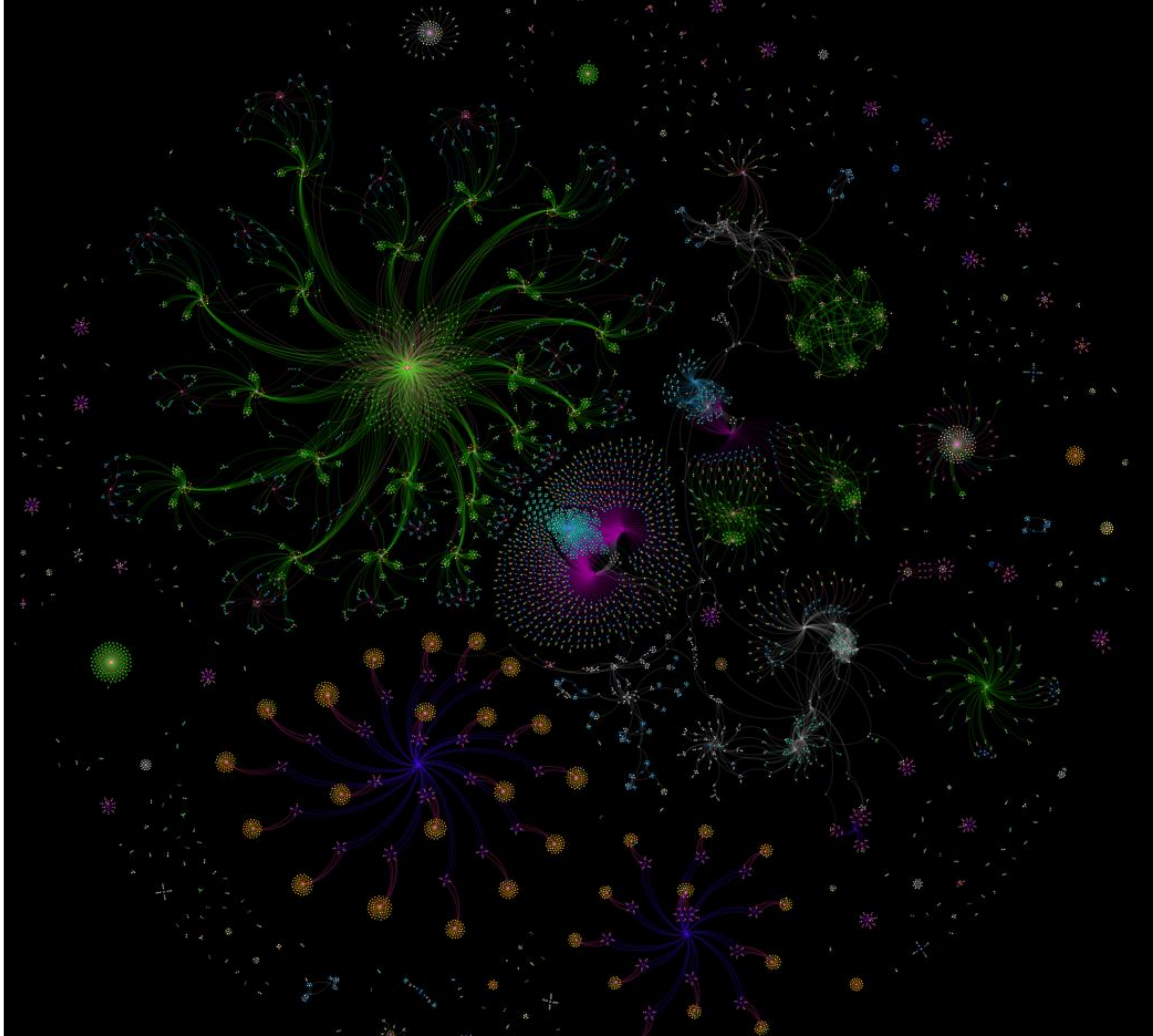
The nervous system of the facility

Scale, Complexity & Interdependencies:

A synchrotron consists of thousands of interconnected components

This is the accelerator control system at MAX IV

Each beamline has its own beautiful graph



EPICS and Tango: similar goals, different traditions

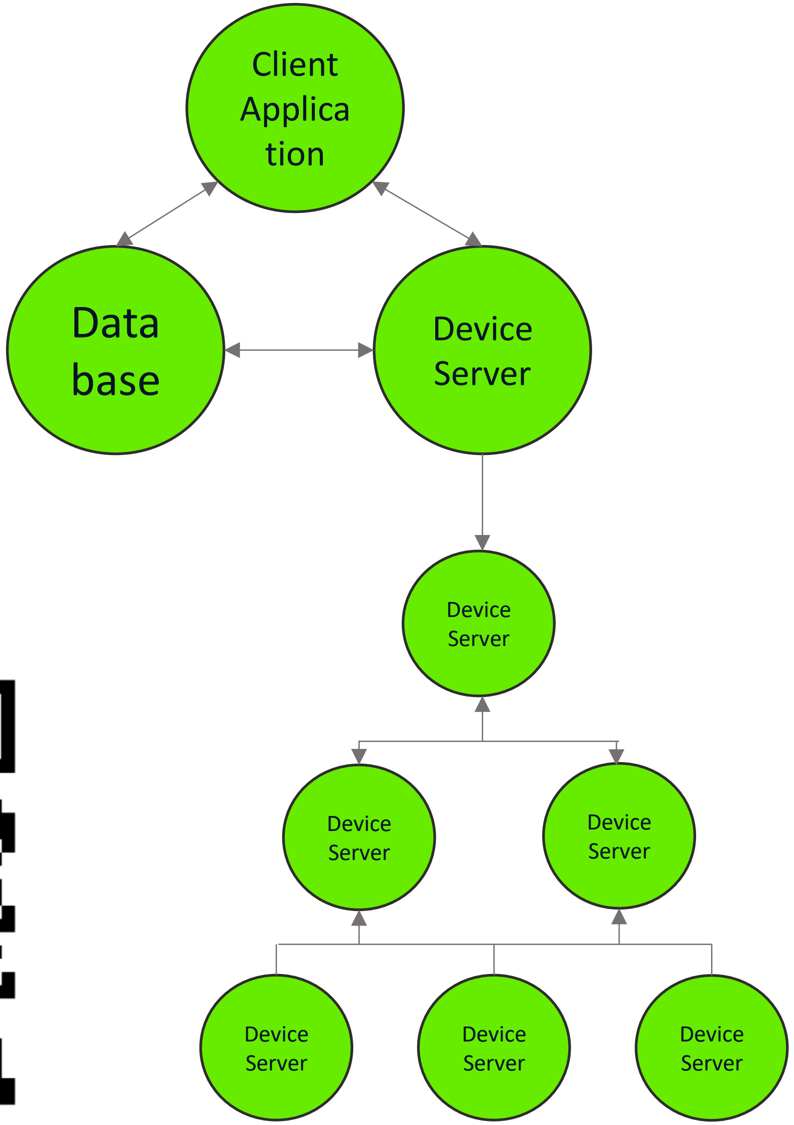
Two successful open-source ecosystems for building distributed control systems in scientific facilities.

Aspect	EPICS	Tango Controls
Origin	Accelerator & large-experiment control community	ESRF & the European synchrotron community
Core abstraction	IOC, records & Process Variables	Device servers, devices, attributes & commands
Communication	Channel Access & PV Access	Tango protocol (CORBA / ZeroMQ)
Mental model	Facility as many named process variables	Facility as interacting devices
Typical use	Accelerators, neutron sources, synchrotrons, large experiments	European synchrotrons & scientific facilities, telescopes

> *If you understand distributed controls, you can learn both.*

CONTROL SYSTEMS LIKE EPICS AND TANGO

- TANGO uses hierarchies of devices to manage complexity simply
- Hardware access is managed in a process called a Device Server
- Devices can store configuration in a database permanently
- Clients look up devices in the database and use the Tango protocol to communicate with them

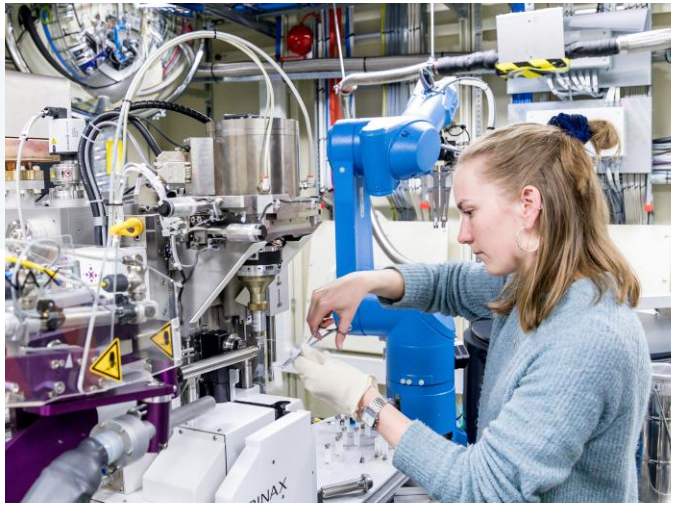


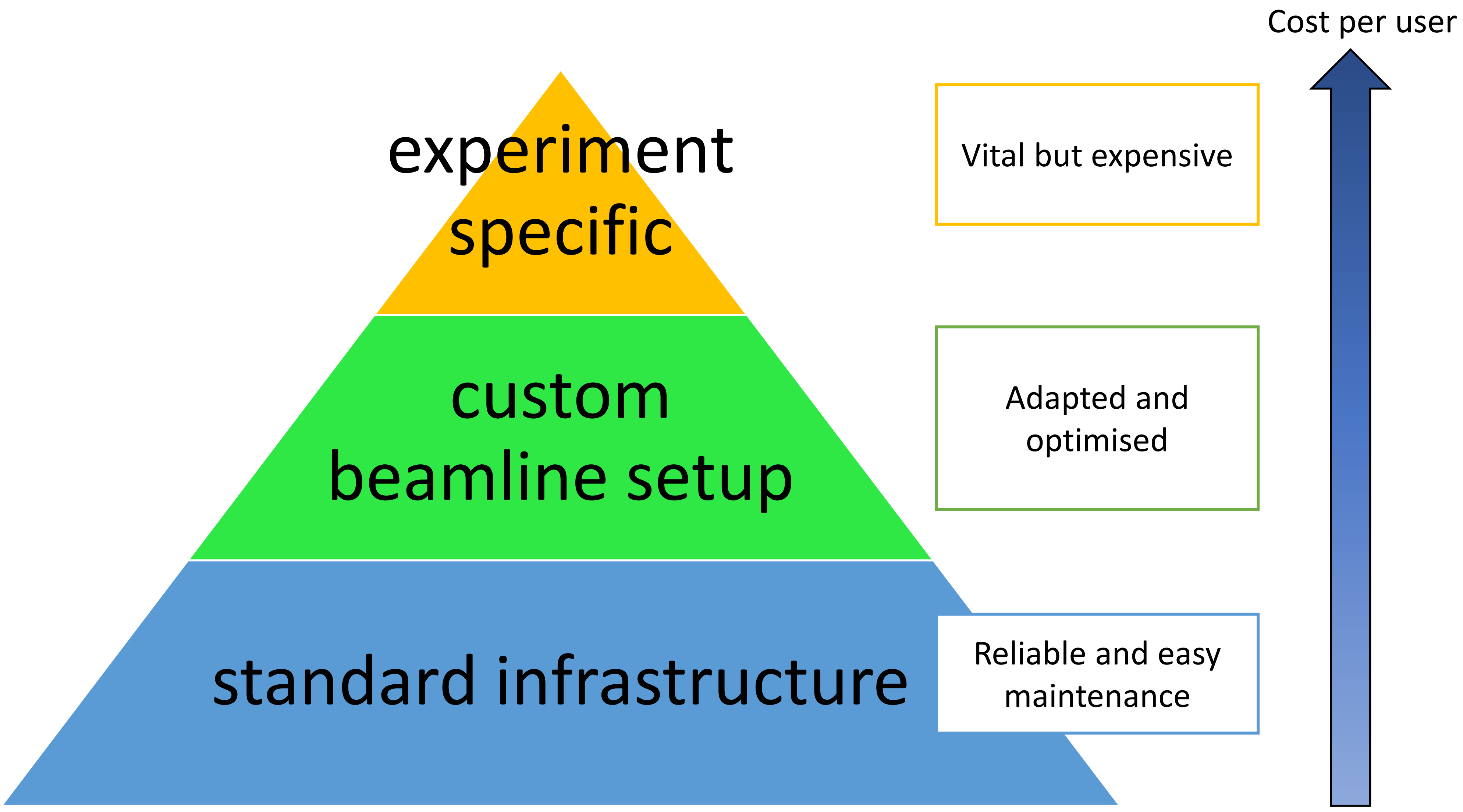
From stable systems to scientific output

The control system is not the final goal — it is part of the chain of discovery.

Reliable controls → **Stable beamlines** → **Successful experiments** → **Trustworthy data** → **Scientific insight & societal value**

> *A good control system enables the success of the researchers*

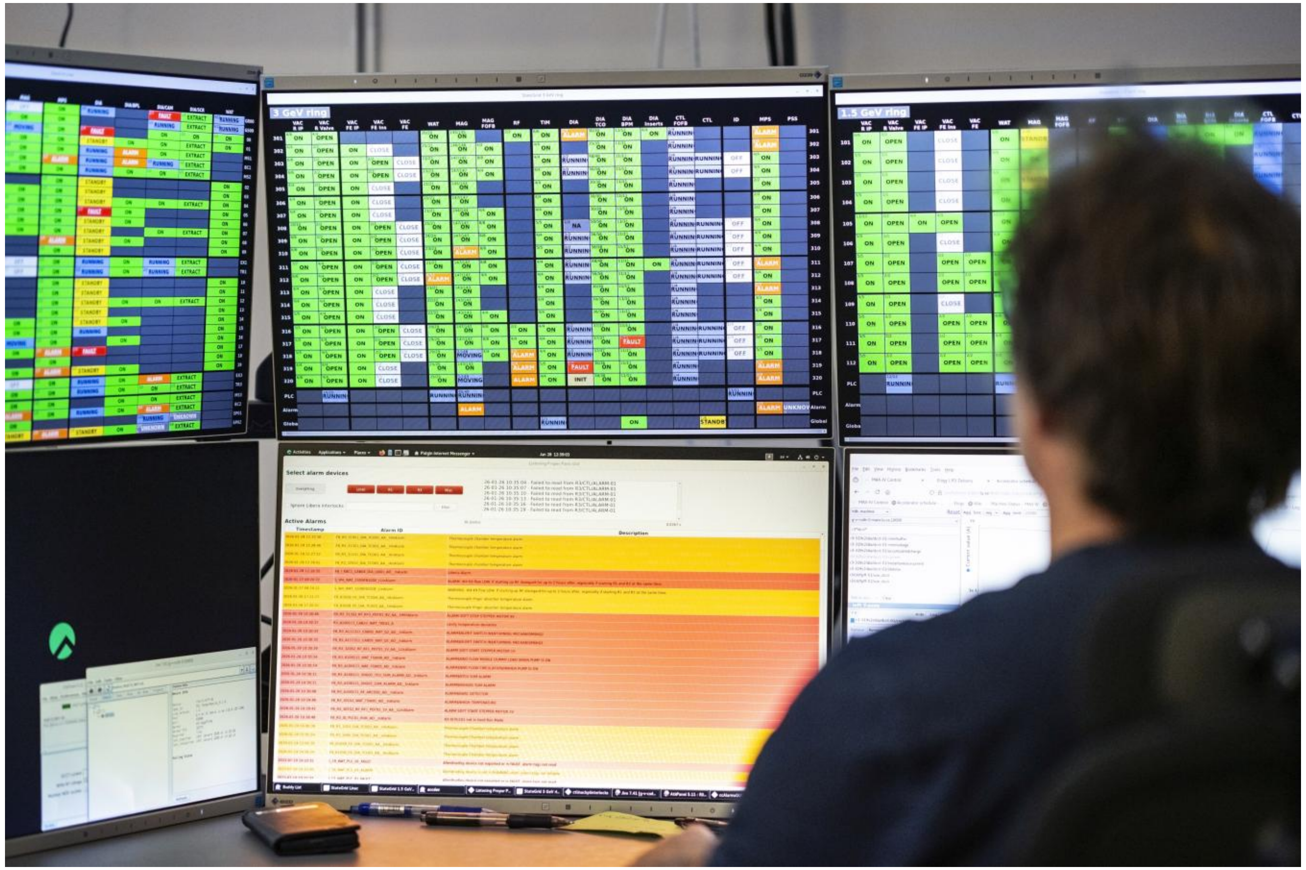



Cost per user
experiment specific
custom beamline setup
standard infrastructure
Vital but expensive
Adapted and optimised
Reliable and easy maintenance

Control system trends for the future

- Standardisation and collaboration
- Remote control and more automated experiments
- Real-time feedback from analysis into experiment control
- AI-assisted optimisation, diagnosis & decision support
- Digital twins and richer models of facility behaviour
- Repeatability and traceability

> *Automation and AI need reliable controls before they can become useful.*



Why learn EPICS?

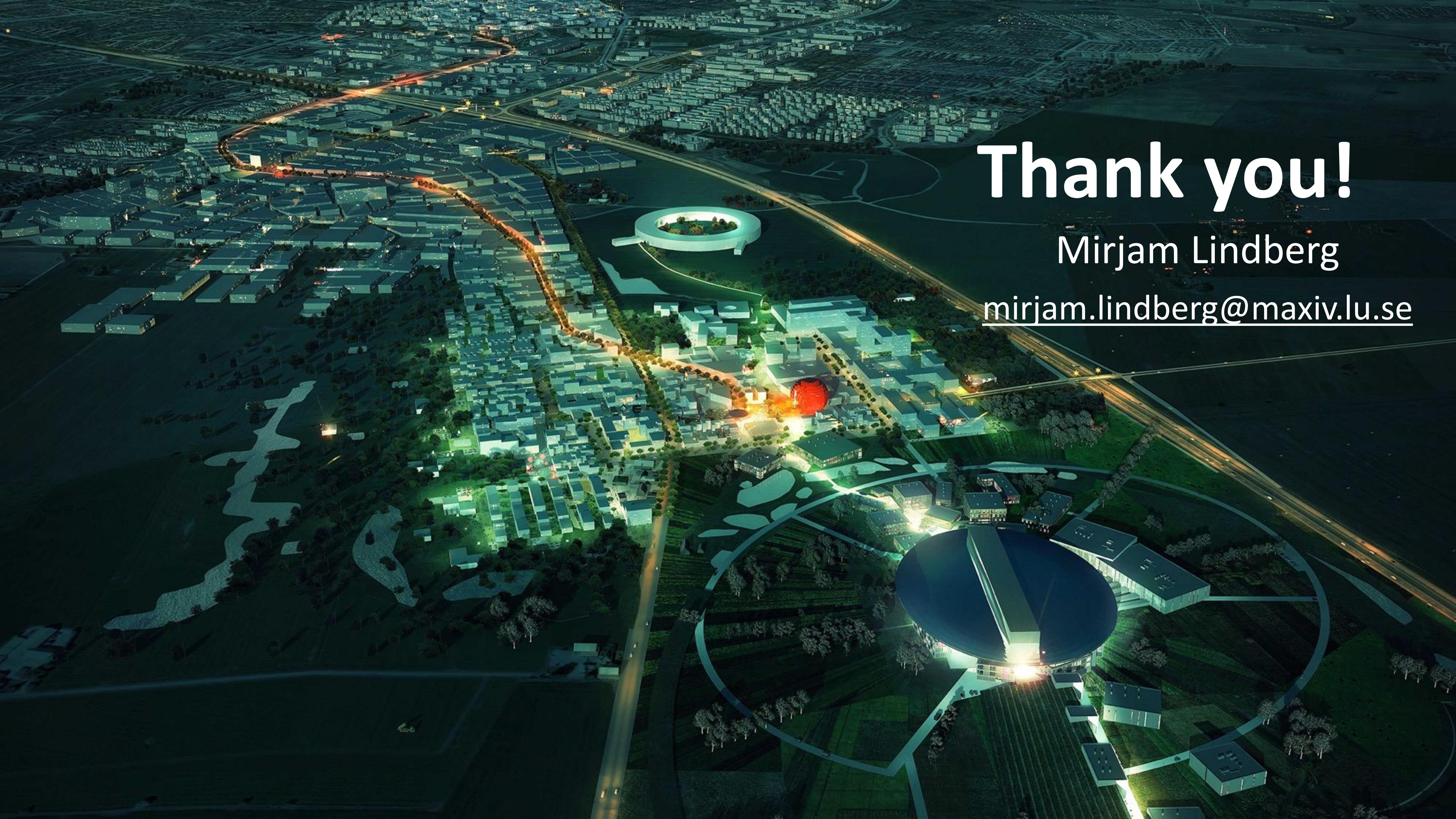
> *Learning EPICS is learning one language of modern scientific infrastructure.*

- You will learn how facility-scale systems are built and operated
- You will connect software, hardware, data & scientific purpose
- You will work with concepts used across international facilities
- You will join a community that keeps scientific infrastructure alive

Community

More than 700 control system experts attending the 2025 ICALEPCS conference in Chicago.

Next year at CERN!



Thank you!

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