SOLEIL SYNCHROTRON

SOLEIL Automated Systems

SOLEIL II
La science éclaire l'avenir
Science lights up the future

Outline

- Introduction
  - SOLEIL Automation
  - Standardization
  - Software Integration for Process/System Automation

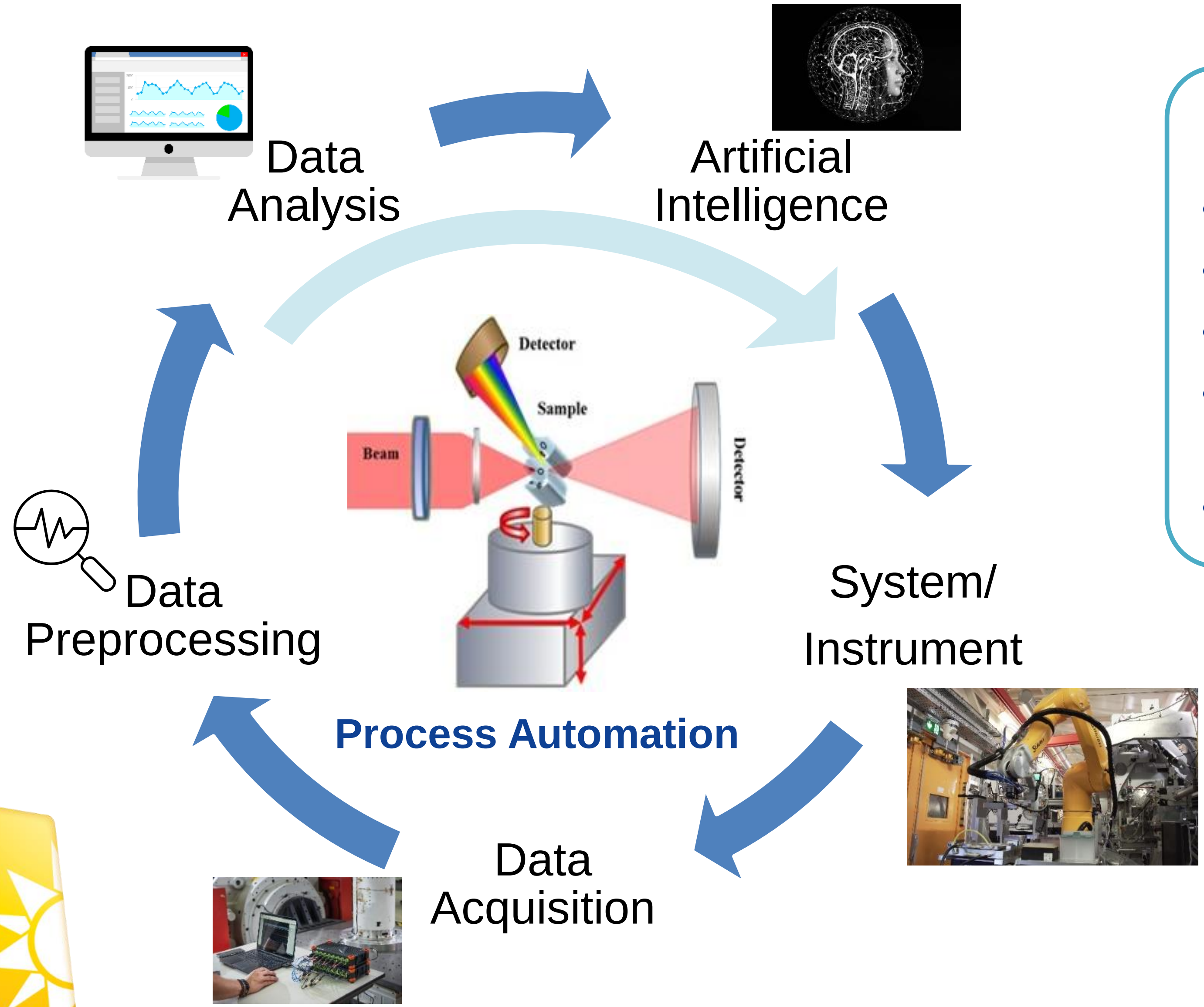
- Robotic and Mechatronics Systems Automation
  - 6 Axis Robots at SOLEIL
  - CRISTAL Beamline Automation
  - NANOSCOPIUM Beamline Automation
  - SWING Beamline Automation
  - MARS Beamline Automation
  - LUCIA Continuous Energy Scan

- Perspectives

INTRODUCTION

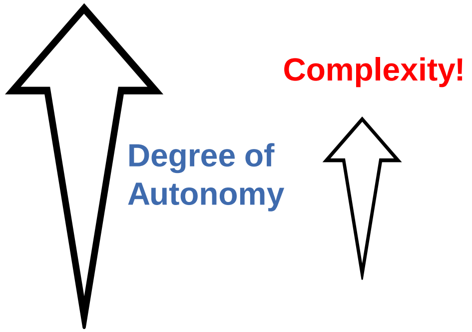
SOLEIL II
La science éclaire l'avenir
Science lights up the future

Towards a higher degree of automation of instruments/processes



Benefits of Automation

- Simplify the experimental procedures
- Improve sample throughput
- Reduce workload
- Accurately gather suitable experimental data
- Optimize the beam time



SOLEIL Automation

With a large variety of experimental techniques, sample environments and with increasing demands on operational performance, the **process/system automation** become more complex and pose significant hardware and software integration challenges.

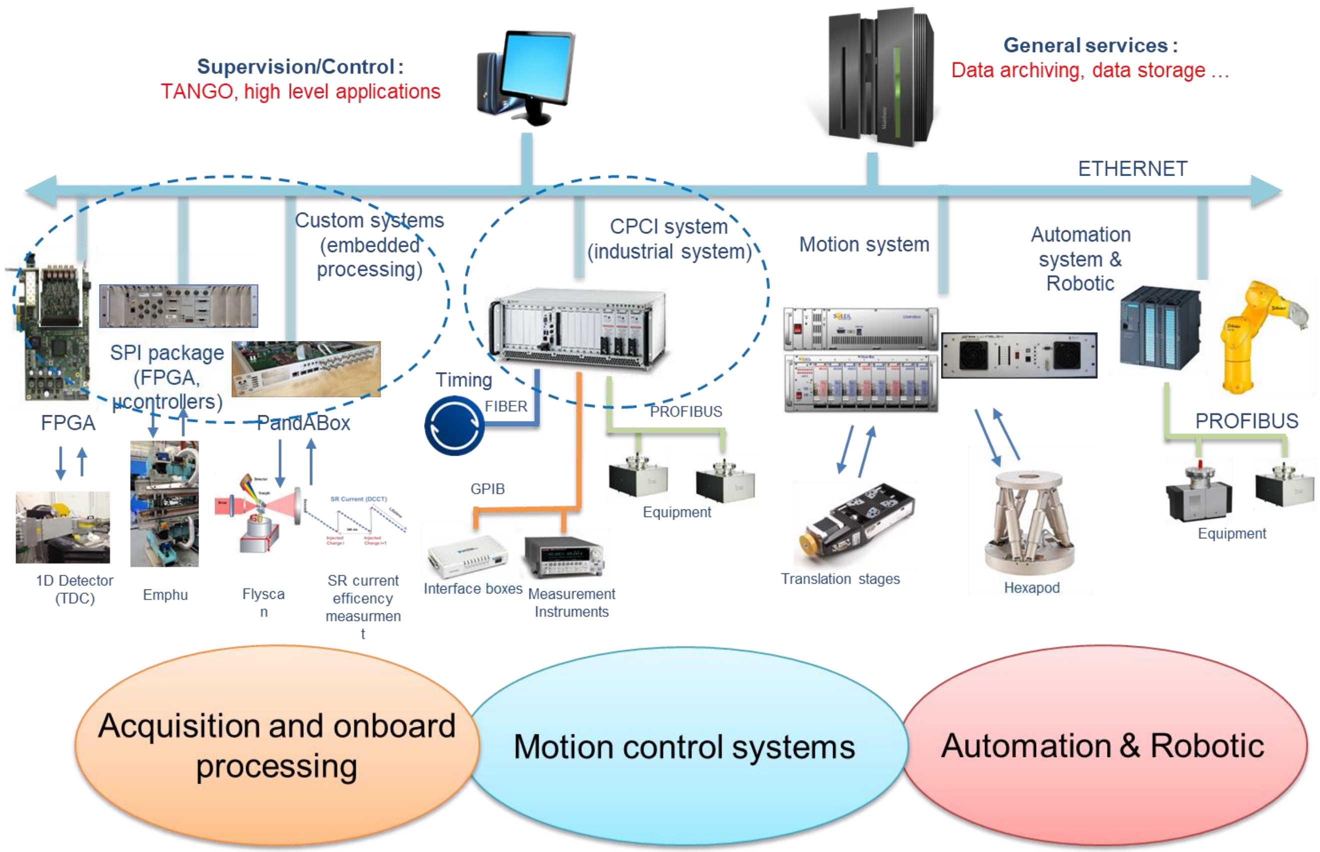
↓

The standardization of hardware and software then allows us to:

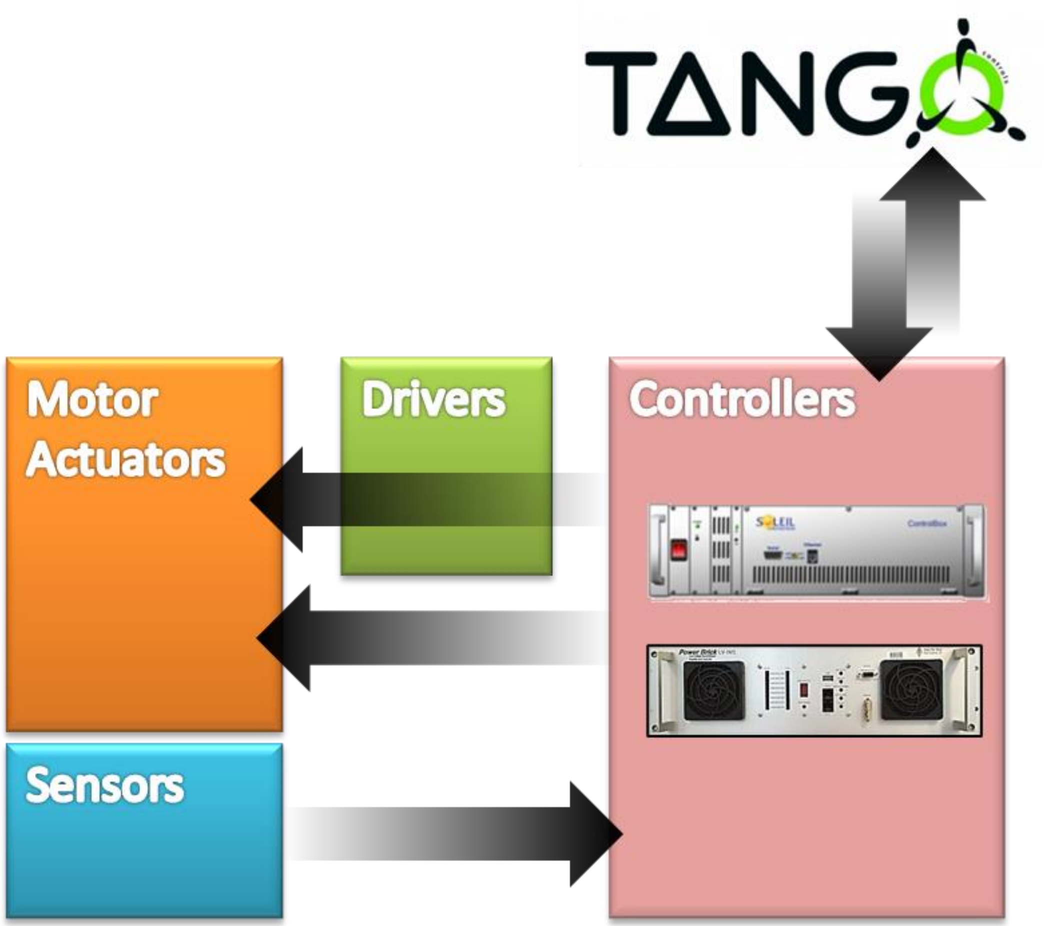
- ✓ Have proficiency in integration
- ✓ Have better operational management
- ✓ Have the possibility of evolving applications
- ✓ Improve support and maintenance

Standardization

- Hardware and Software for control are **standardized** as much as possible:
- DAQ and FPGA systems
- **Motion controllers**
- **6 Axis robot arms**
- Programmable Logic Controllers



In this presentation the focus will be on motion controllers and robotic arms

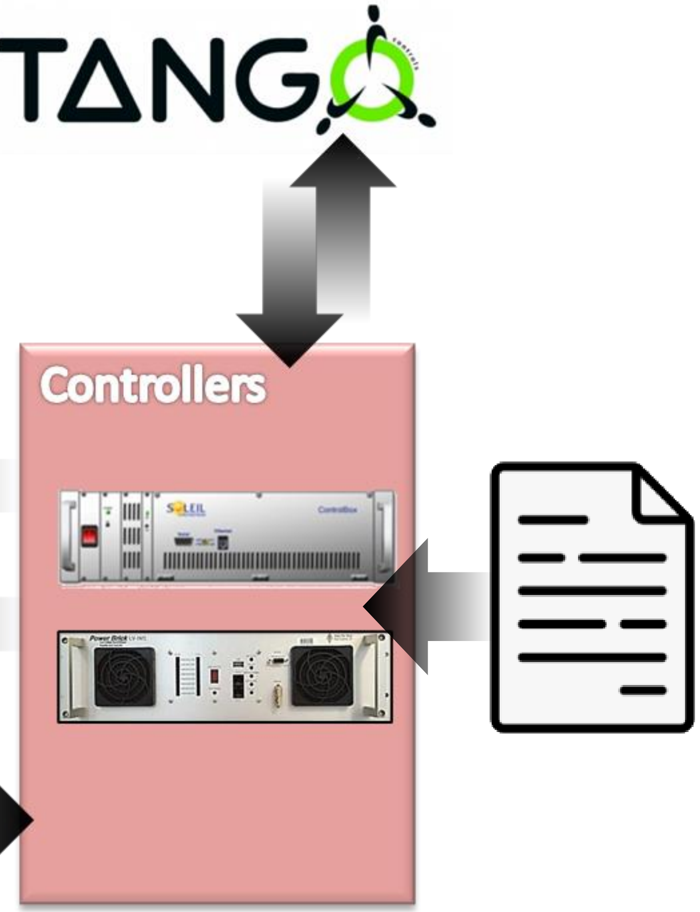


SOLEIL employs a standardized 2-controller solution

- Standard applications (Galil)
- High-performing applications (Powerbrick)

Motion Controller Standardization

Microcode Templating



Standardized Microcode Templates that:

- Interfaces with TANGO control devices
- Employs system configurations
  - That are robust, secure, and well tested
    (ex: stepper motor configurations with well defined current limits)
  - Flexible and modular
    (ex: any kind of motor configurations with any kind of encoder configuration)
  - Cuts down configuration/installation times
- Implements low-level functionalities such as:
  - **Motor/actuator securities:** dynamic current-handling (VaccuumMode), heat management (duty cycle)
  - **Advanced control network handling:** controller-to-controller (MACRO, EtherCAT*), controller-to-driver (MACRO, EtherCAT*), controller-to-other (EtherCAT*)
  - **Kinematics:** analytical equations, Look-Up-Tables (LUT)
  - **Buffered/automated low-level trajectories:** analytical equations, LUT
  - **Anti-collision systems:** predictive, reactive

* ongoing

Microcode Template highlight examples (listed by application):

Nanoprobe [SWING]

- Interferometry integration
- Multi-axial kinematics
- Controller-to-Controller communication
- Automated & buffered fast low-level scans (equations & LUT)

Detector Support [MARS]

- Controller-to-Driver communication (external high-powered amplifier)
- Multi-axial kinematics
- Anti-collision

DCM [SAMBA, MARS, SIRIUS]

- Multi-axial kinematics
- Motor securities (VaccumMode)

Hexapods [GALAXIES, LUCIA]

- Multi-axial kinematics

Diffractometer [SIRIUS]

- External amplifiers
- Multi-axial kinematics (hexapods)
- Controller-to-Controller communication

Synchronization Monochromator – Insertion Device [LUCIA]

- Controller-to-Controller communication
- Multi-axial kinematics
- Controller-to-Driver communication (external high-powered amplifier)

Tracer Project [METROLOGIE]

- Automated & buffered fast low-level scans via LUT
- Multi-axial kinematics

6 axis Robot Standardization

This standardization defines a robotic standard (6 axis robot arms) on both hardware and software.

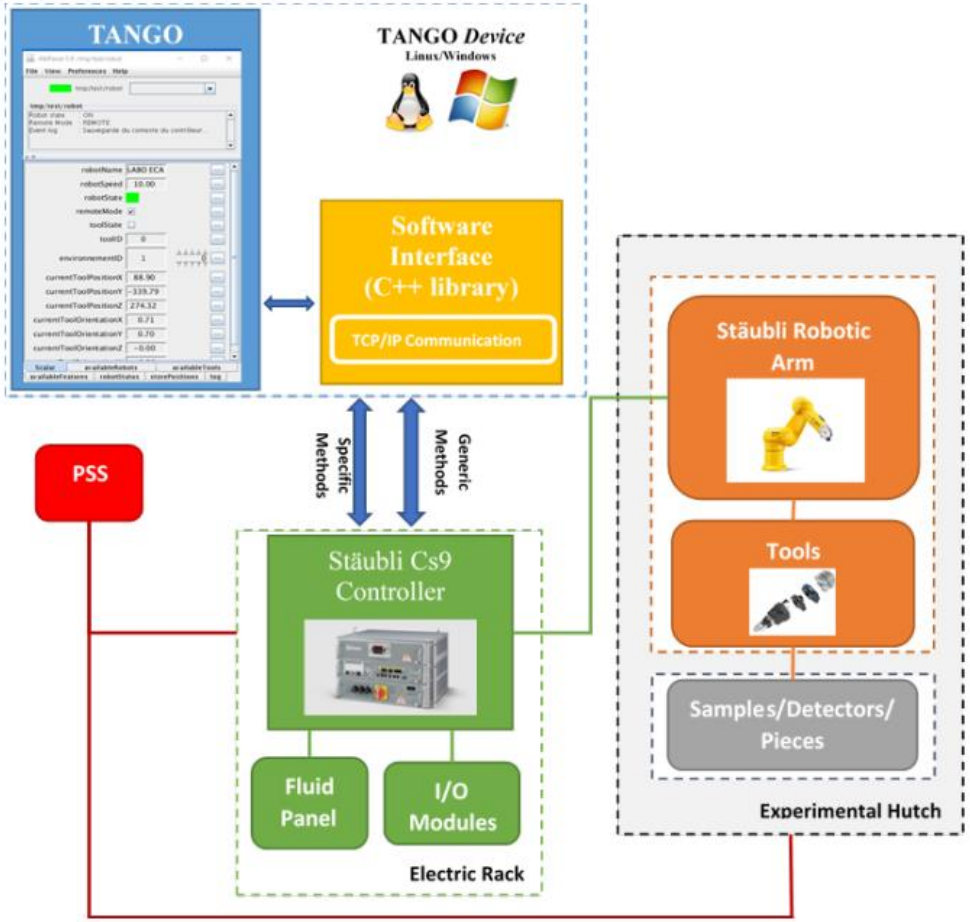
Hardware

Brand: Stäubli

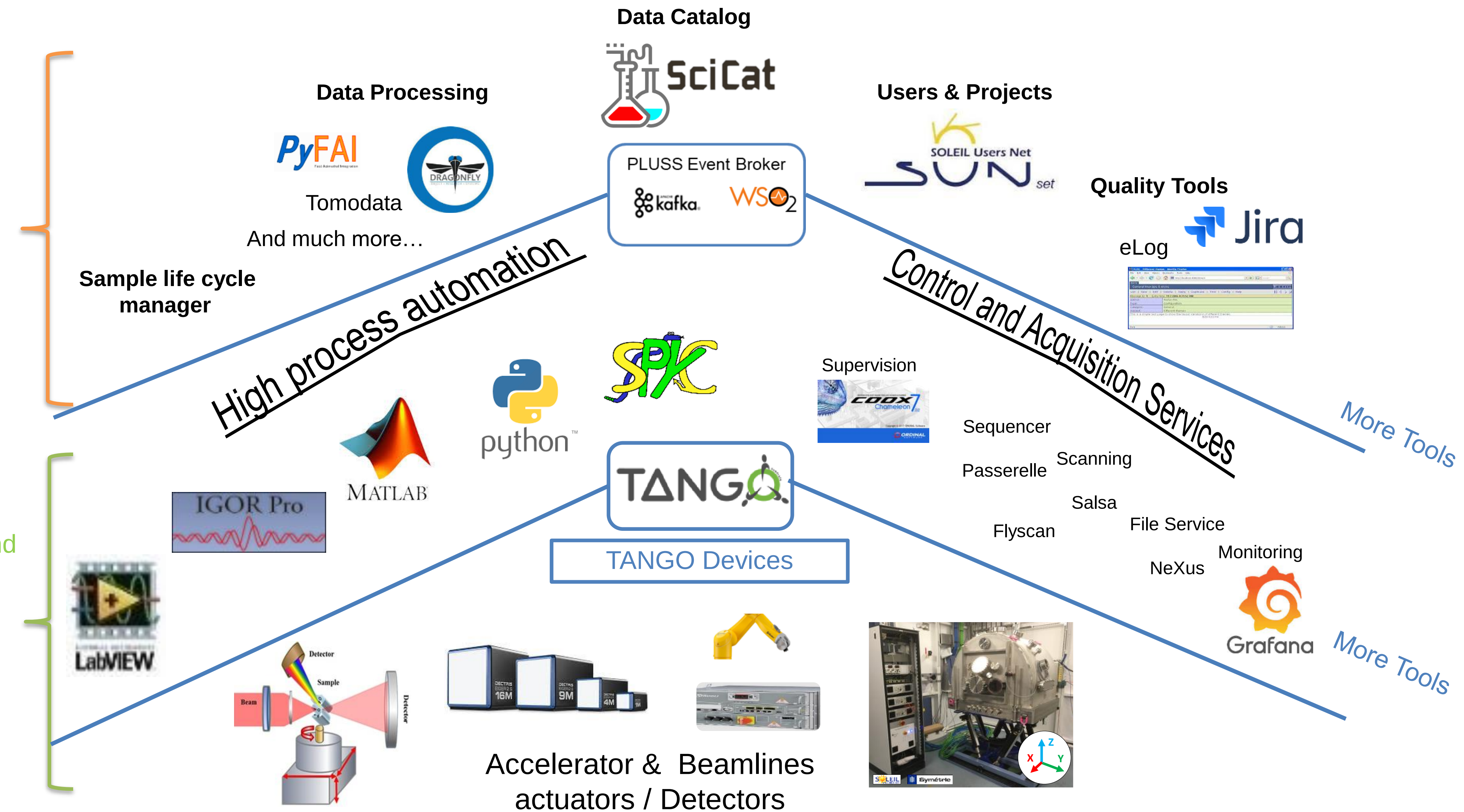
Controller: Cs9

Software

- C++ Library
  - Link between the Cs9 controller and Tango
- Generic Methods:
  - Genetic attributes and commands
- Specific Methods
  - Application-specific tasks.



Tools for Process Automation



ROBOTIC AND MECHATRONICS SYSTEMS AUTOMATION

La science éclaire l’avenir
Science lights up the future

6 Axis Robot Arms

Automation is identified for a large variety of experimental techniques, sample environments based on 6 axis robot arms to: enhance productivity, improve user comfort, minimize risks.

Standardization

Sample Handling
Solid X-ray Diffraction
- PX1 Beamline
- PX2 Beamline

Sample Handling
Powder X-ray Diffraction
- CRISTAL Beamline

2020 A.I.

Undulator Magnet Modules Handling
- GMI Facilities

2021

Detector Positioning
Coherent Diffraction Imaging
- NANOSCOPIUM Beamline

2022

Pipetting Robot
BioSAXS Experiments
- SWING Beamline

2023

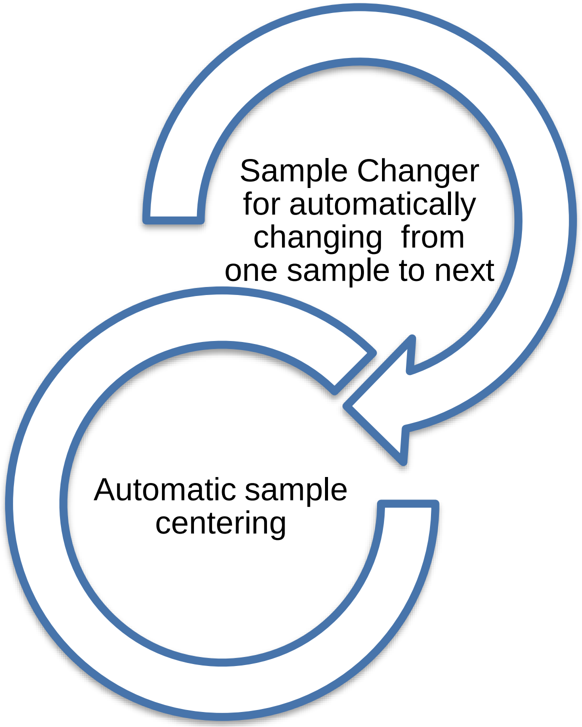
Magnet Supermodules Measurement Bench for Insertion Devices
- GMI Facilities

2023 - 2024

CRISTAL Beamline Automation

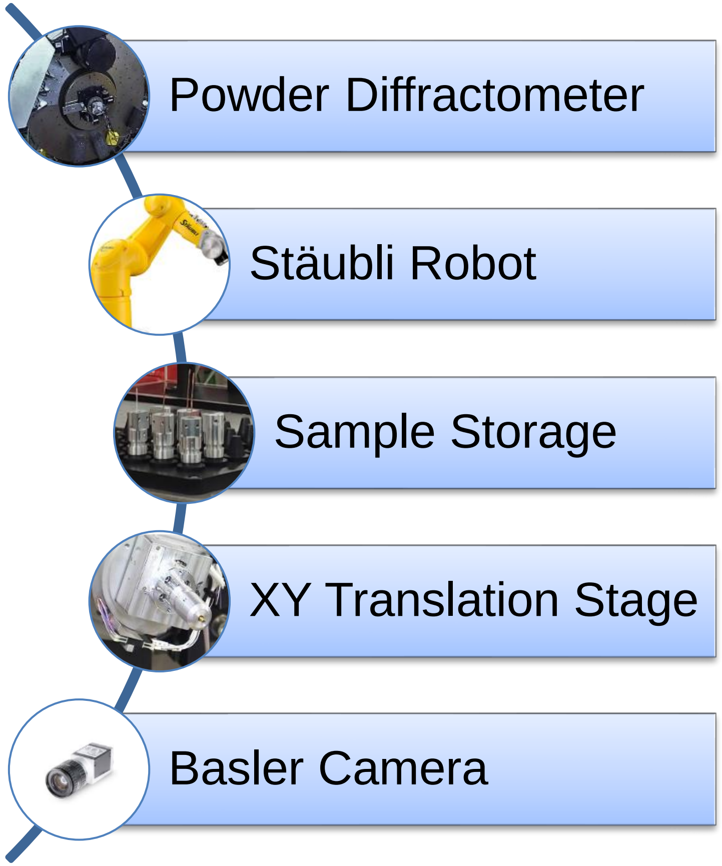
Powder diffraction measurements

Automatic mounting and centering of capillaries



CRISTAL is an Undulator-based X-ray diffraction beamline dedicated to study single crystals and powders.

Hardware



Software

Tango Devices

- Robot Device
- Lima Device
- ControlBox Device
- PyImgProcessor Device

Python and SPYC Scripts

- For high-level robot control
- To center the capillary

CRISTAL Beamline Automation

PyImgProcessor

- PyImgProcessor is a PyTango device which create a configurable sequence of image processing.
- The Device based on Python plug-ins offers image processing called “Actions”.
- The “Actions" connected in a particular order into YAML file will form the image processing sequence.

Tango
File
Camera

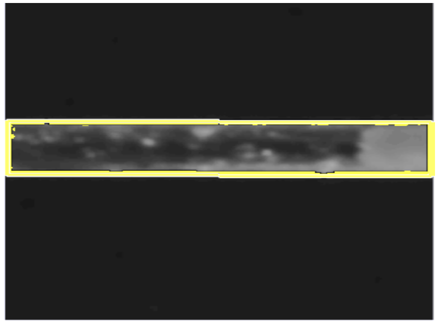
Snap
(Lima/File/vfw/v4l)

Image BG

SubtractBG
(Remove BG)

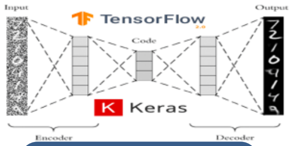
User inputs

Crop
(Define Roi)



CalcHist
(Histogram)

Reduce
(2d ->1d)



DNN model
(Threshold)

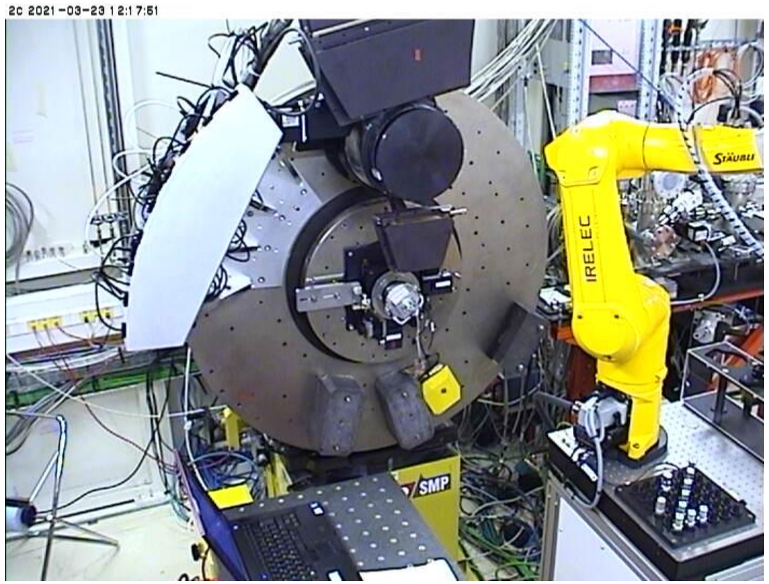
FindContours

MinAreaRect
(Enclosing contour)

Angle

Centroids
(PosX, PosY)

Pos Y



In operation since June 2024

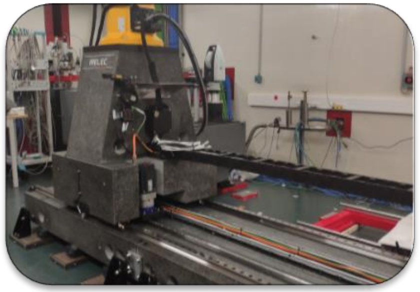
SOLEIL II
La science éclaire l'avenir
Science lights up the future

NANOSCOPIUM Beamline Automation

Automate the 3D positioning of the beamline Merlin4X detector

- Position the detector according to a direction of the diffraction peaks at a variable distance from the sample.
- Ensure that the normal of the detector is pointing towards the sample.

Stäubli TX2-160 Robot



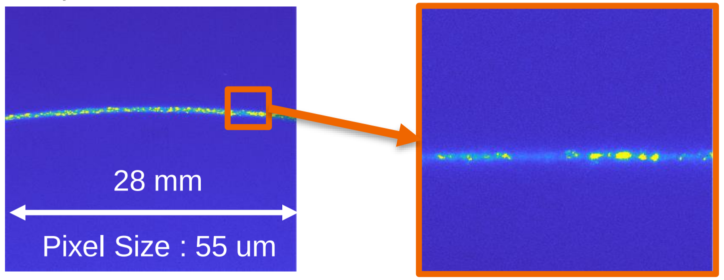
Motorized Translation

Detector Tool:

- Merlin Detector
- Safe collision sensor
- Pneumatic rotation

Scanning X-ray Diffraction Microscopy

det—sample distance : 500 mm   det—sample distance : 3700 mm



The NANOSCOPIUM beamline is dedicated to multi-technique X-ray imaging (5-20 keV) using fast scanning and high spatial resolution (35 nm – 1µm).

Workspace:

- The workspace is a sphere of radius = 1880 mm (from axis 5 of the robot) centered on the translation at a height of 2050 mm.
- The distance between the detector and the sample ranges from 500 mm up to 5500 mm (in some cases).

Accuracy and Precision:

The accuracy of the detector in the whole robot workspace is < 0.200 mm in cartesian position and < 0.0039° in angular position.

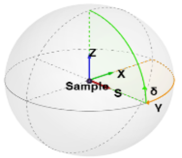
The cartesian precision (repeatability) is < ±0.089 mm.

- **Stability:**
- The maximum value that the detector moves once it is in a desired position is < 0.01 mm over a period of 45 hours (after a stabilization time).

NANOSCOPIUM Beamline Automation

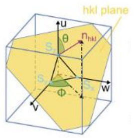
Application operating modes:

Step by Step Scan



Spherical coordinates (r, γ, δ)

γ = [-10°, 150°]; δ = [-10°, 90°]



HKL values*

Coordinate Points:
(h,k,l)
or
(r, γ, δ)

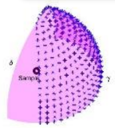
TXT

→ Check if the all points are accessible by the robot

→ Move robot/detector to acquisition point → Start of data acquisition → End of data acquisition → Move robot to Parking Position

For each coordinate point

min_γ, max_γ,
min_δ, max_δ,
increment_ γ, increment_ δ



Sphere Scan

Fast δ and γ scan at 500 mm

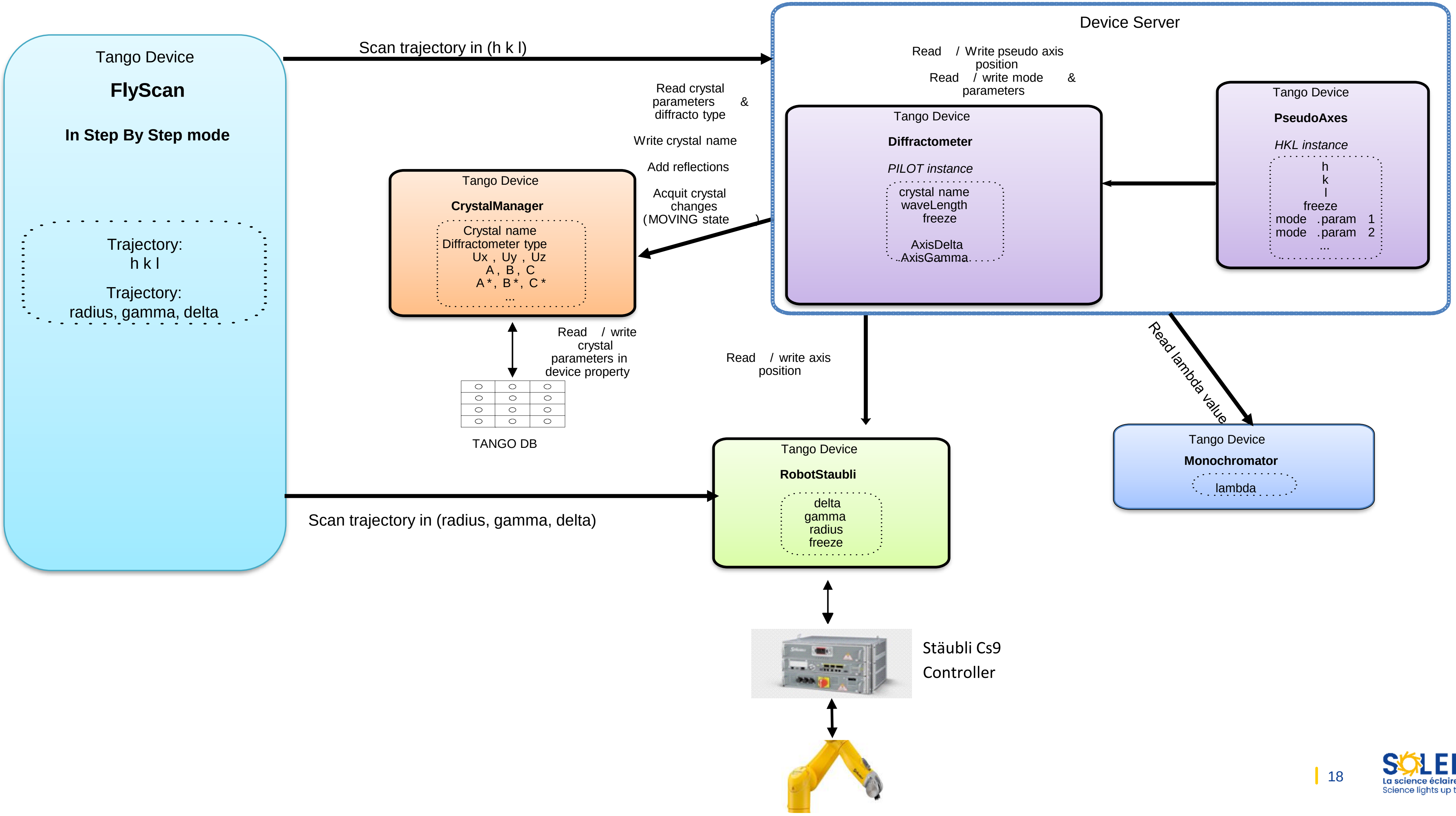
→ Move robot/detector to the initial acquisition point → Data acquisition → Move robot to the next acquisition point → Data acquisition → … → Move robot to the last position → Data acquisition → Move robot to Parking Position

*https://people.debian.org/~picca/hkl/hkl.html#org8c1e1fa

SOLEIL II
La science éclaire l'avenir
Science lights up the future

NANOSCOPIUM Beamline Automation

6 axis Robot Software Integration

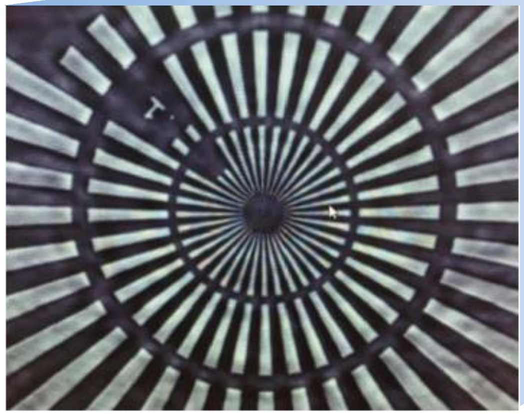


SWING Beamline Automation

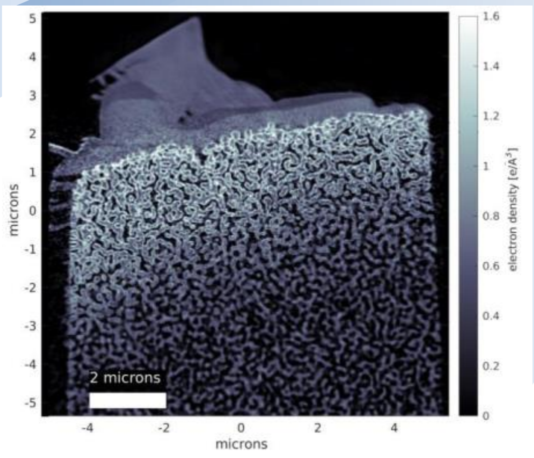
Nanoprobe System

The SWING Nanoprobe system was installed (11 DOF) in 2018 to provide:

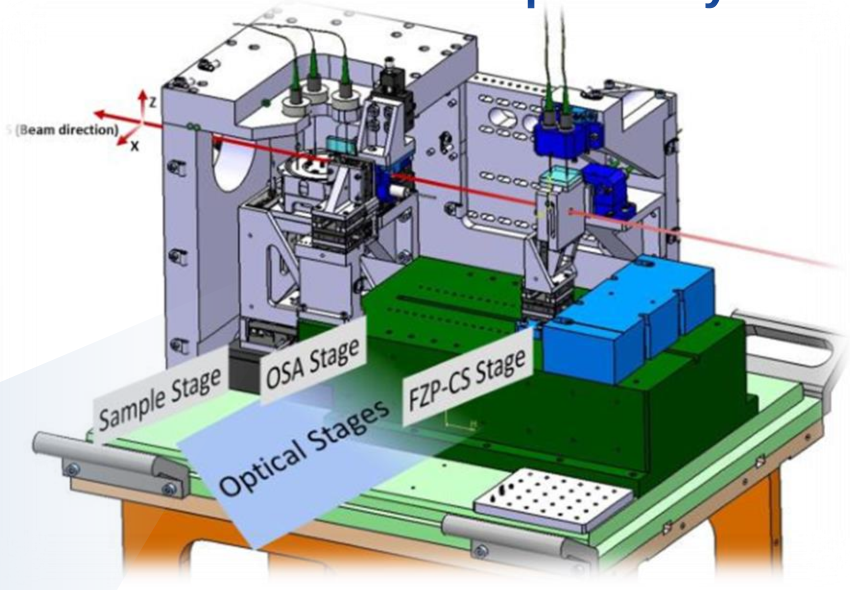
- **Semi-automatic 2D- and 3D- ptychography scans with nanometric level resolution**



2020: 2D image, Siemens star
Resolution ~= 17nm



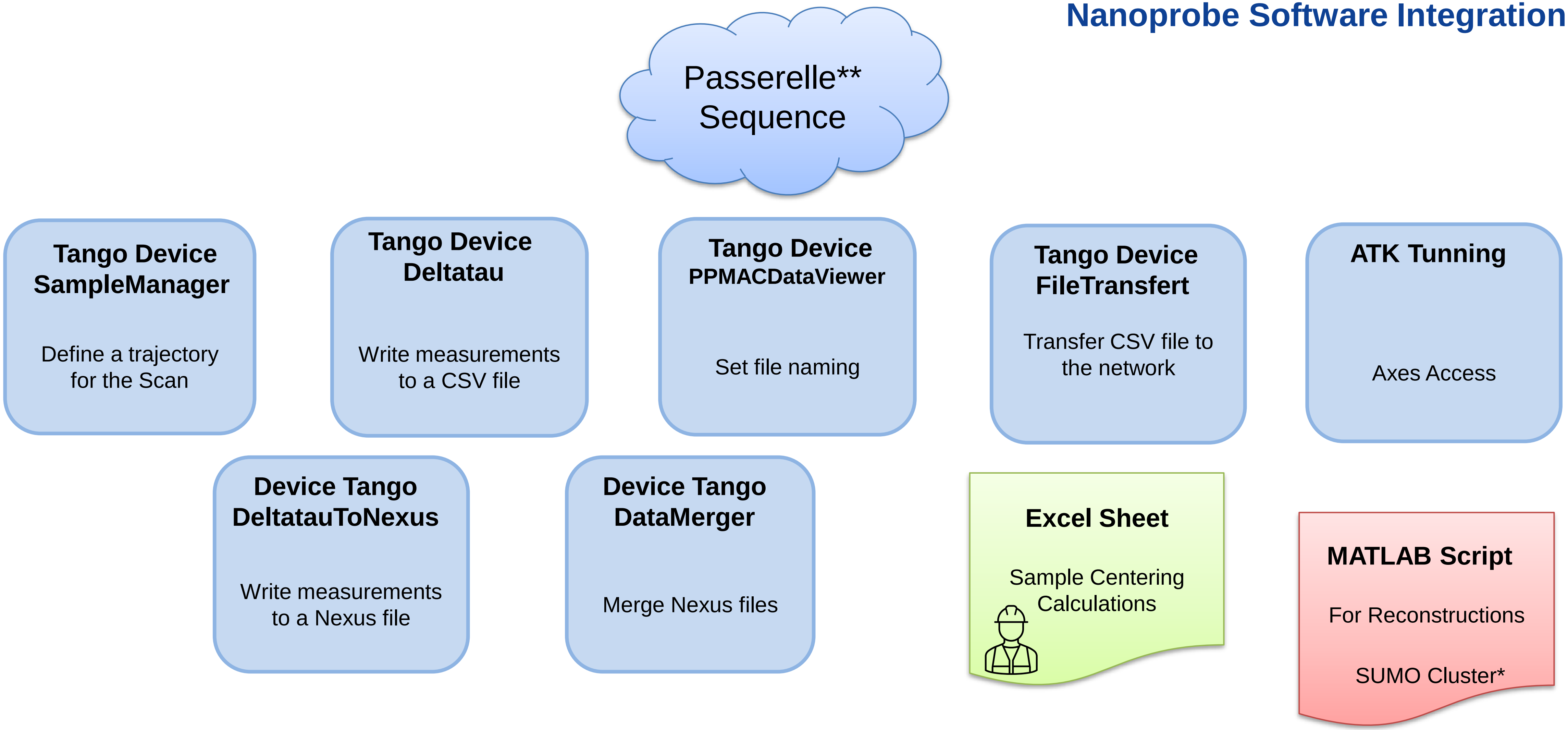
2020: 3D tomogram,Silica sample
Spatial resolution ~= 40nm



- Interferometry integration
- Multi-axial kinematics
- Controller-to-Controller communication
- Automated & buffered fast low-level scans (equations & LUT)

SWING Beamline Automation

Nanoprobe Software Integration

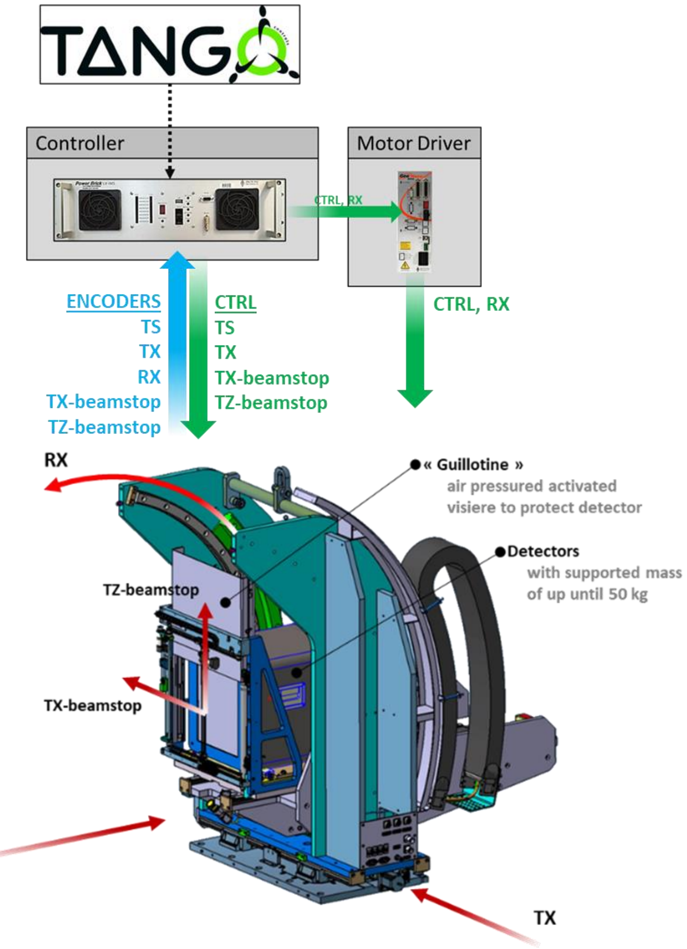


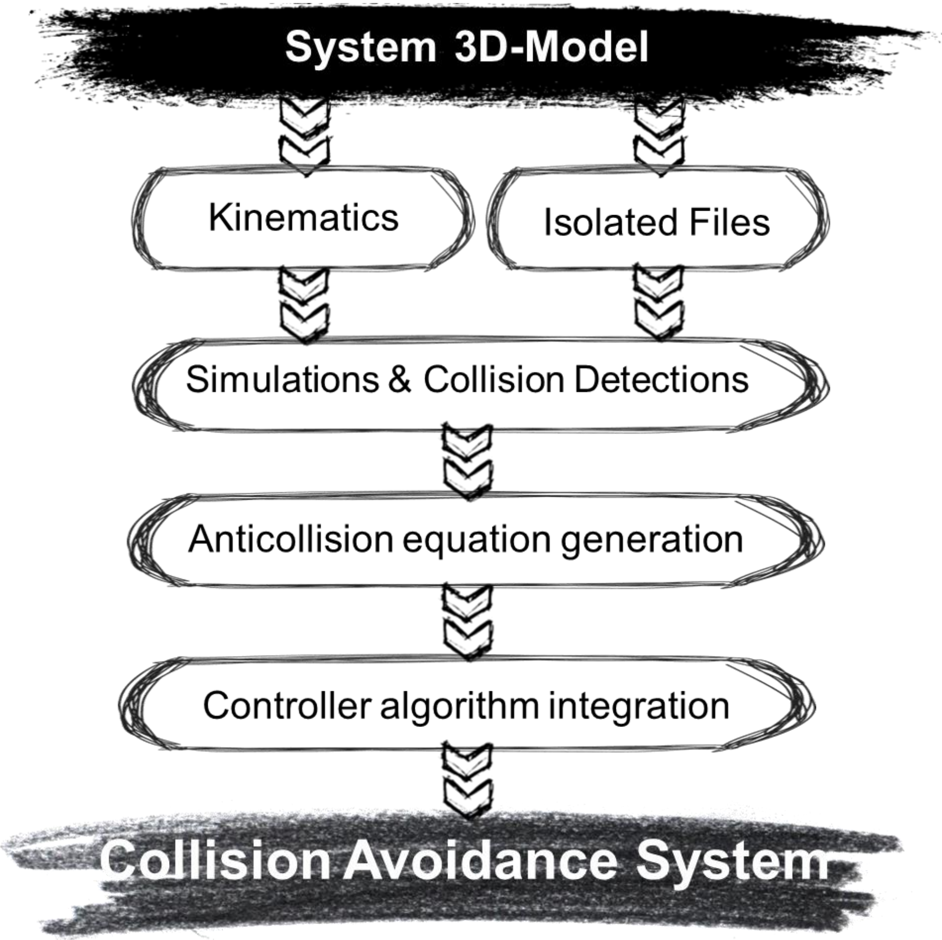
*SUMO: It is a computing cluster formed by 13 computing nodes :

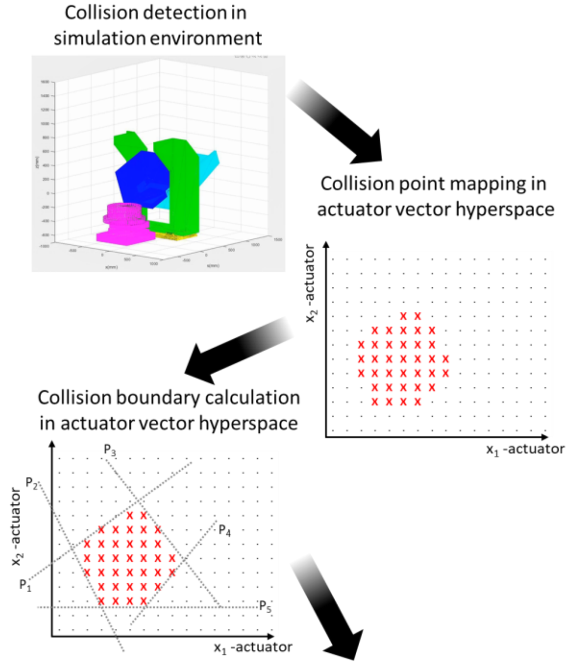
- 2 x Intel E5-2680v3 (12C-2,5GHz)
- 128GB DDR4 2133Mhhz
- 2x NVIDIA Tesla K80 → 4 GP-GPU

**Paserelle: is a framework used to graphically design sequences of actions performed on equipment and acquisitions.

Automatic positioning of a 2D detector system with a **collision avoidance** system.







Collision algorithm generation:

The geometrical closed halfspace:

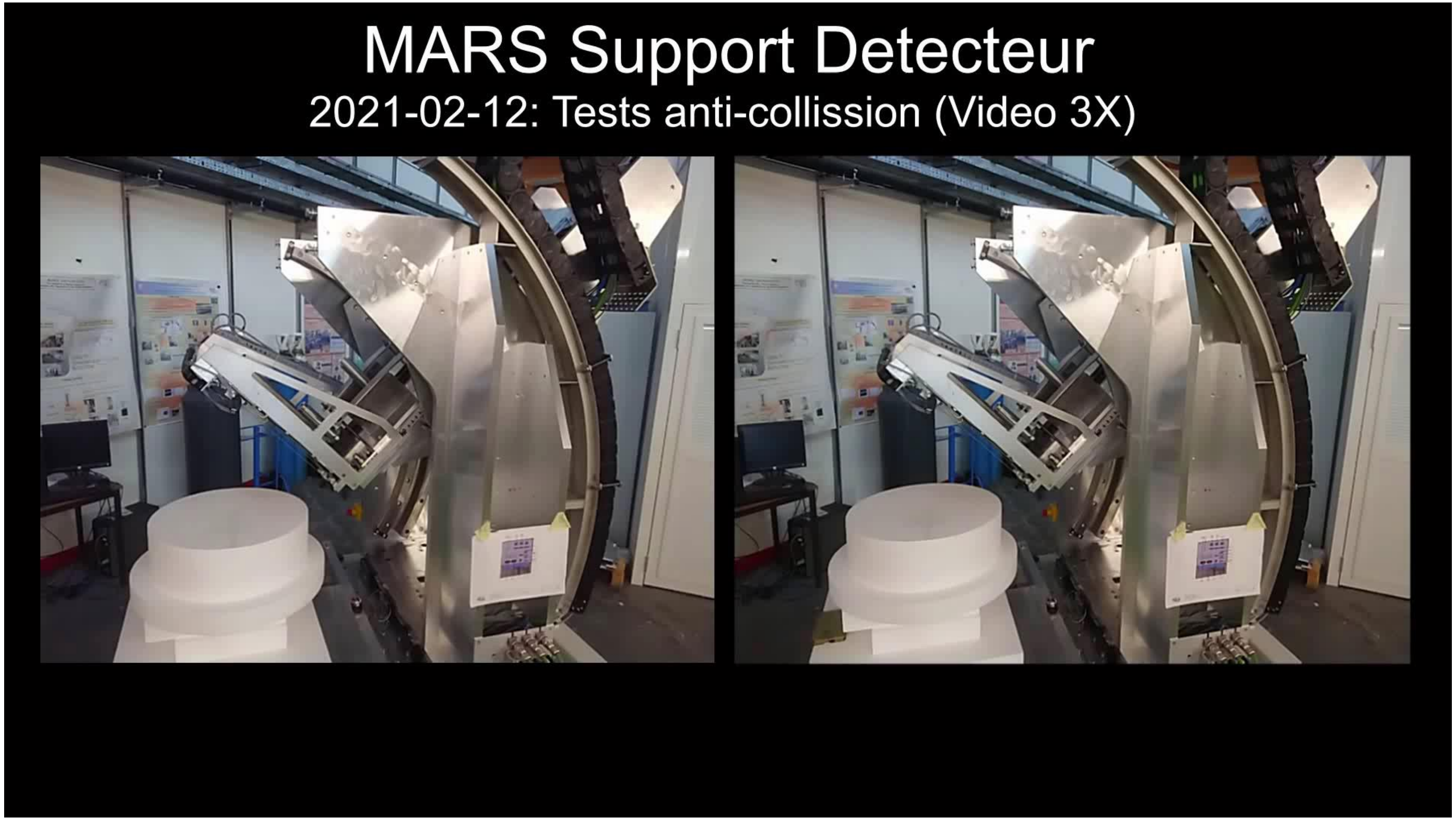
$$P_{hs} < 0$$

$$\text{where: } P_{hs} = a_{m,0} + \sum_{1}^{n} a_{m,n} x_n$$

for each enclosing line P_m: $m \in \mathbb{N}$
in actuated dimensional space: $n \in \mathbb{N}$

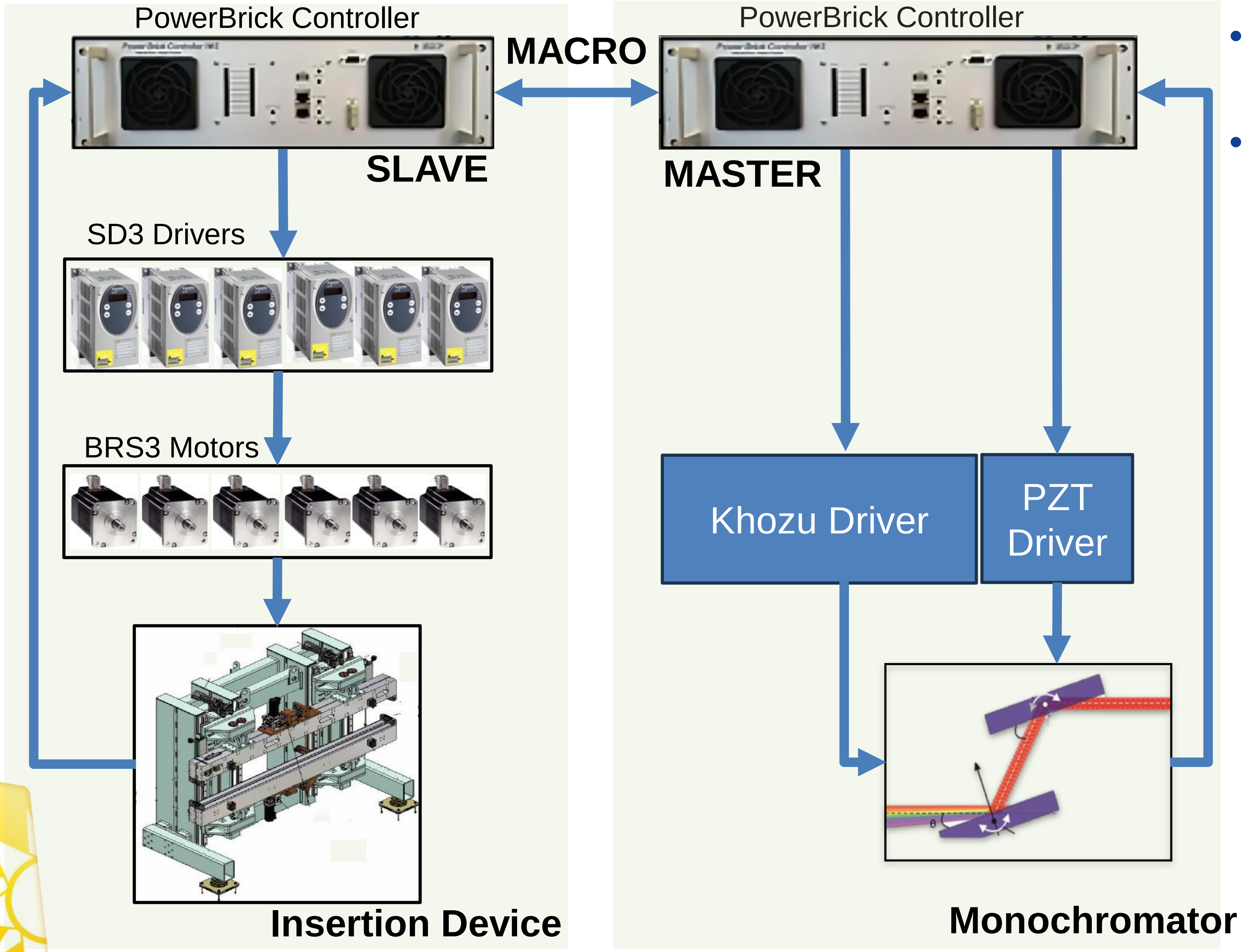
MARS Beamline Automation

Results

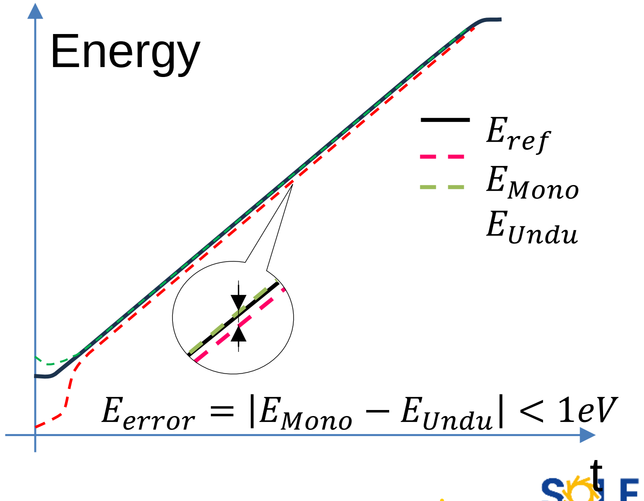


Synchronization Monochromator-Insertion Device

EXAFS Flyscan LUCIA

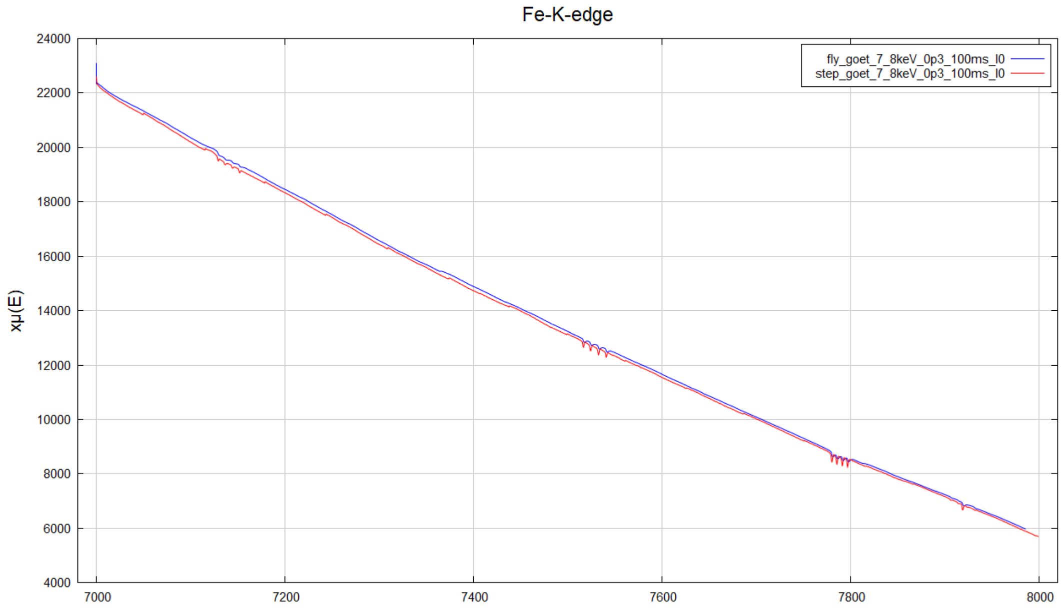


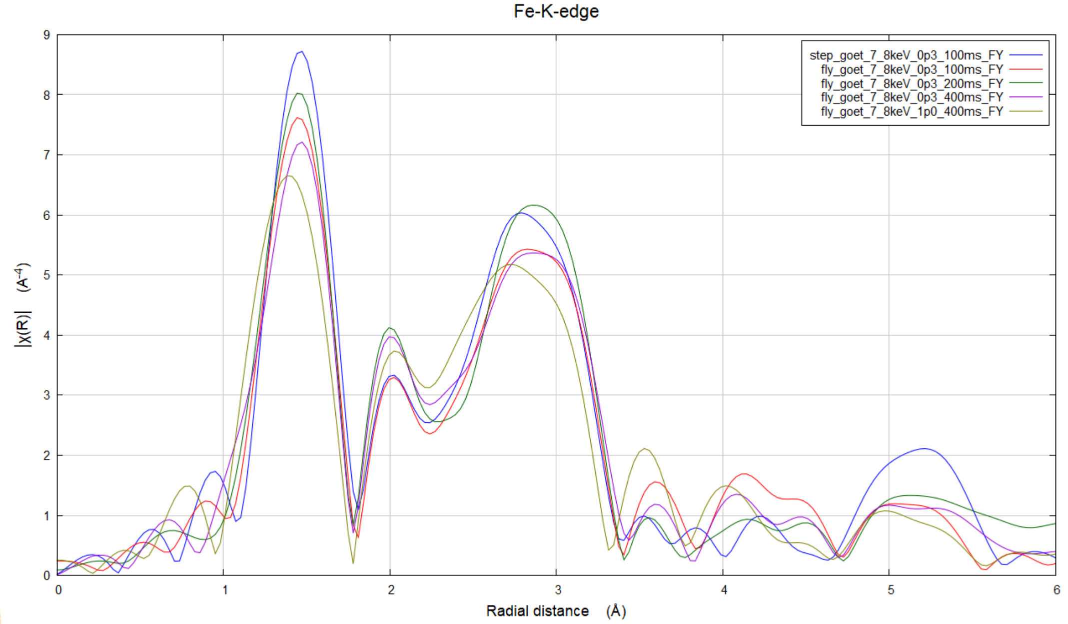
- "Individual" mode: each system is controlled separately.
- Synchronization mode:
  - All motors are in closed-loop control.
  - PBR Master creates E_{ref}.
  - PBR Master controls the motors of the "Mono" and the ID to make the E_{Mono} and E_{Undu} converge to E_{ref}.



Synchronization Monochromator-Insertion Device

Preliminary Results





- First tests carried out in September 2024.
- The EXAFS spectra in step scan or flyscan are almost superimposable.
- The Fourier transforms of the EXAFS spectra in steps scan or fly scan are similar.

Next steps:

- Optimization of the controller parameters must be carried out.
- Reliability and robustness must be achieved.

SOLEIL II La science éclaire l'avenir Science lights up the future

Roadmap for Automation

Beamline Automation as a Multi-robot system

- **Applications**
  - Continuation of robotic applications installations:
    - On beamlines,
    - For test bench and repetitive tasks for SOLEIL II.
  - For in-vacuum applications, solution based on specific developments are considered
  - **Automatic beamline alignment & sample centering**
- **Technical developments**
  - Sensor data fusion including industrial vision functionalities:
    - Avoid collisions, automatic generation and trajectory tracking.
  - **Digital Twins**
  - Collaborative robots (human-robot interaction)
- **Automatic pipeline for control and data processing**
  - **Ewoks evaluation**

Automation Towards Autonomous Instruments

Autonomy can be divided into different levels depending on how the system cooperates with humans*:

1 Human Operated
Direct result of human-initiated control inputs.

2 Human Assisted
The system can perform activity in parallel with human input.

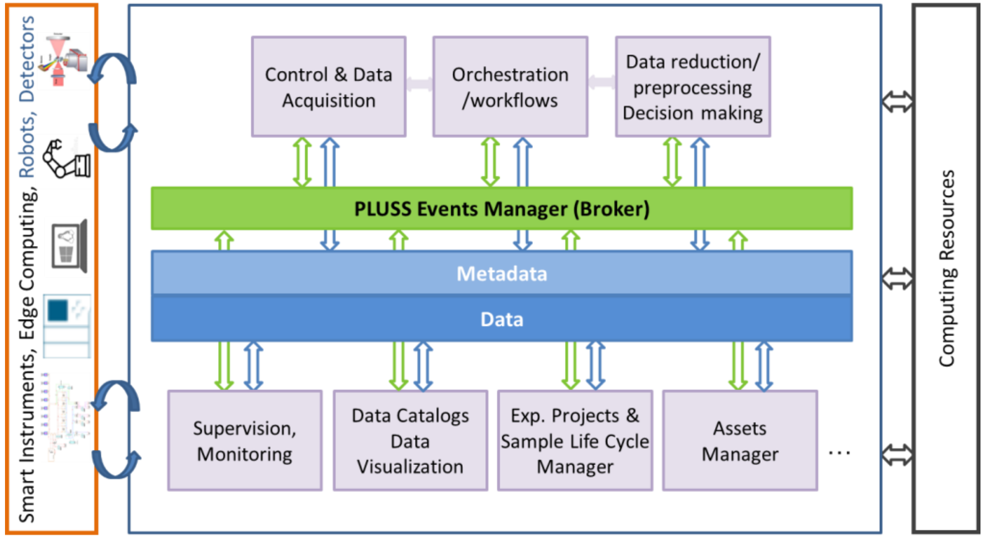
3 Human Delegated
The system can perform limited control activity on a delegated basis.

4 Human Supervised
The system can perform a wide variety of activities given top-level permissions of direction by human.

5 Mixed Initiative
Both the human and the system can initiate behaviors based on sensed data.

6 Fully Autonomous
The system requires no human intervention to perform any of its designed activities.

Information System Transformation



Core Data Architecture

- **Increase the degree of autonomy in our processes/systems**
- **Instrument design as a system of systems**
  - Control
  - DAQ systems
  - Data processing
  - Artificial Intelligence
- **Easily accessible**
  - Data
  - Metadata


THANK YOU