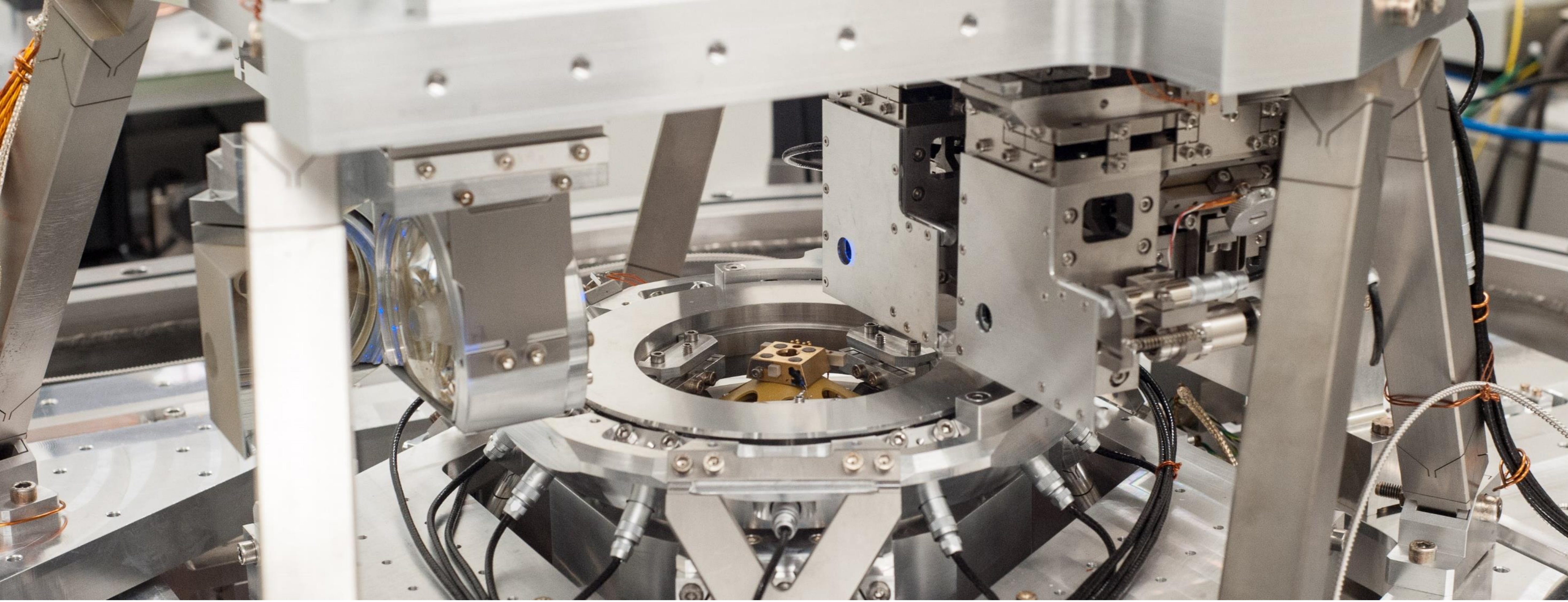


Experimental stations for synchrotron radiation beamlines

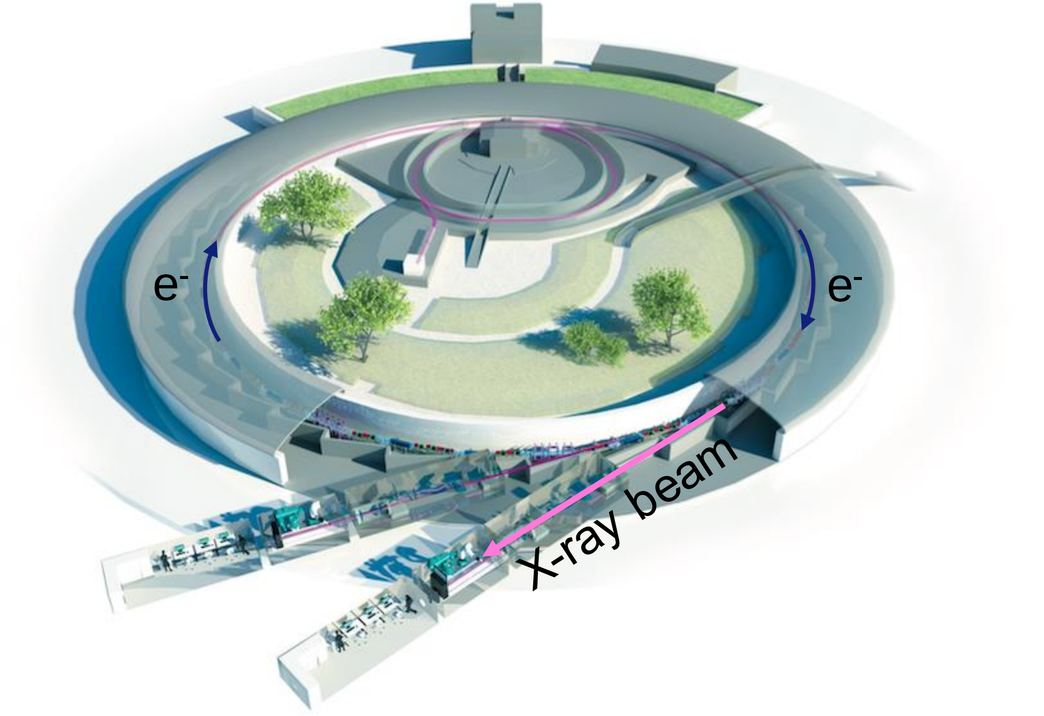
François Villar - ISDD Mechanical engineering group

8th EIROforum School on Instrumentation - May 14, 2024 - ESO/EUROfusion Garching

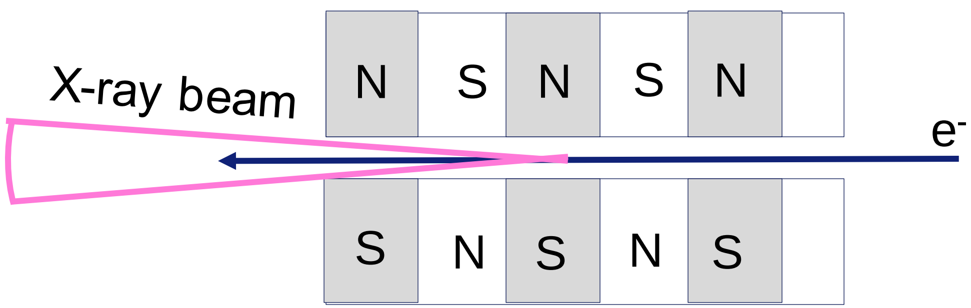
OUTLINE

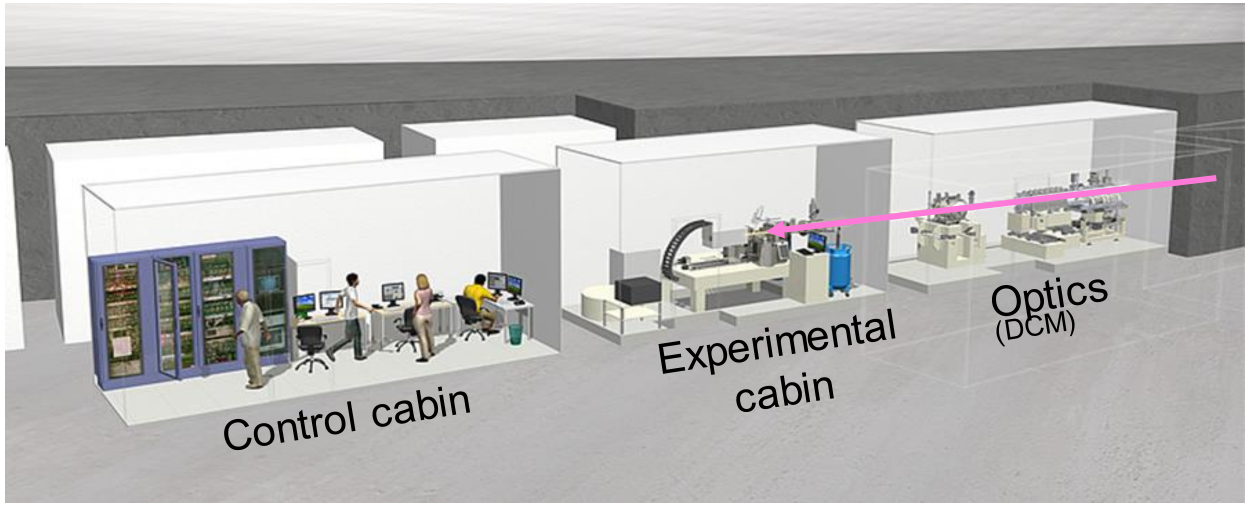
- ➢ Introduction
- ➢ Challenges
- ➢ Some solutions
- ➢ Focus on guiding error correction
- ➢ Typical results

WHAT ARE WE TALKING ABOUT ?

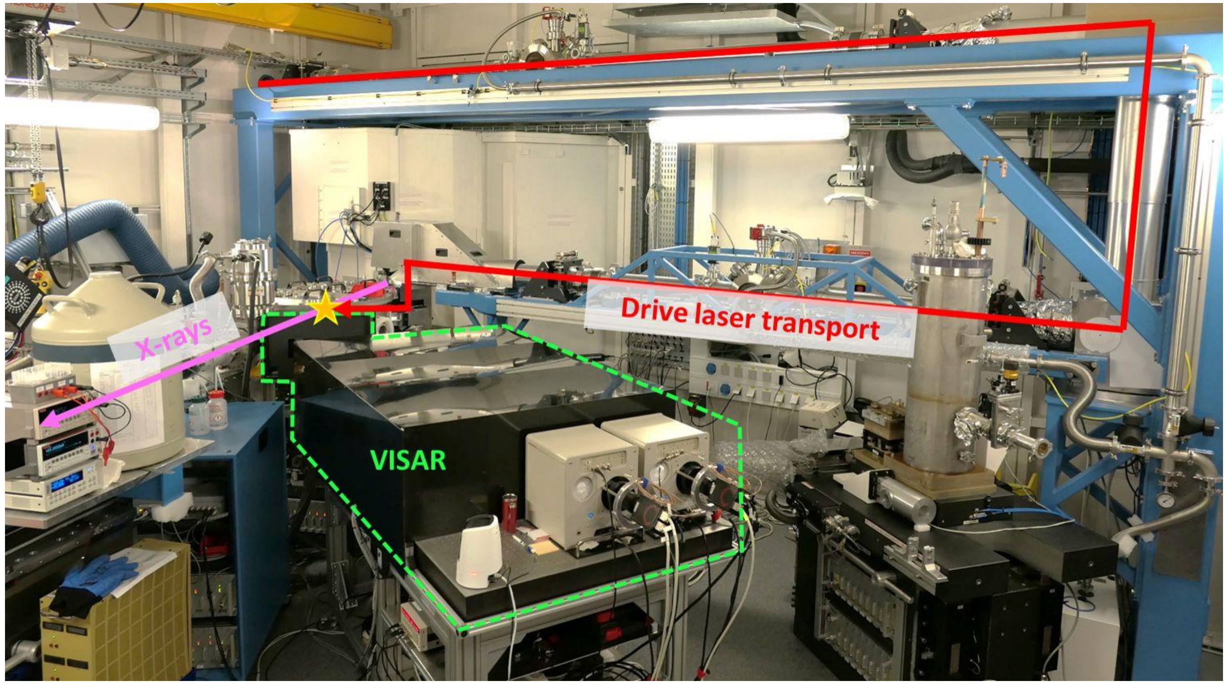


undulator



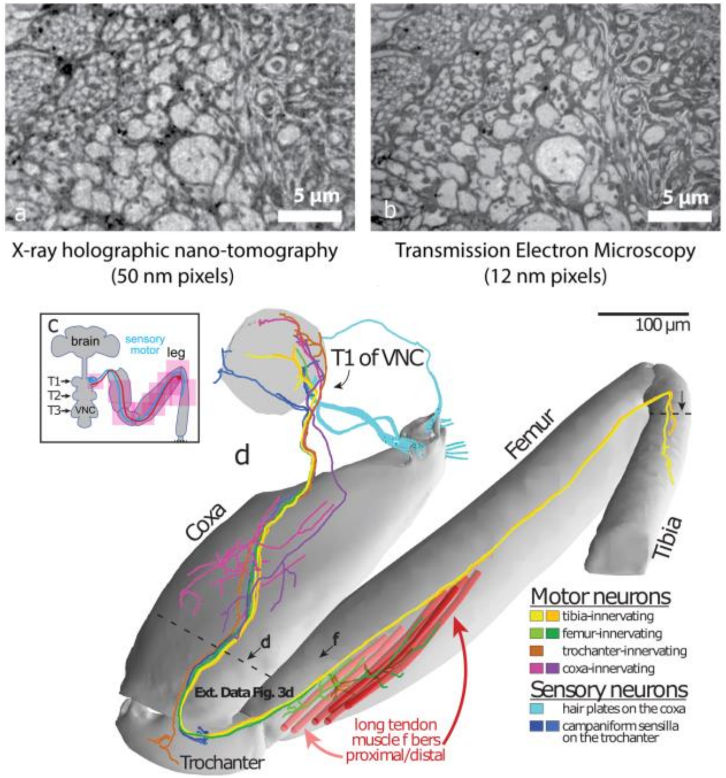


ID24 Experimental cabin



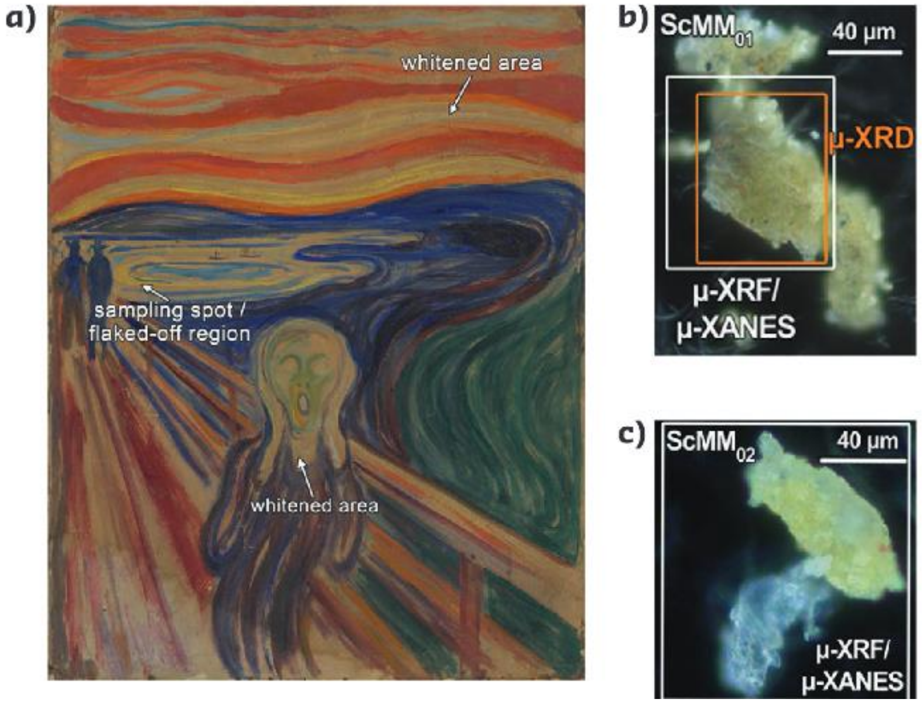
WHAT IS IT MADE FOR ? A *FEW* EXAMPLES

Study of neurons in fruit fly leg



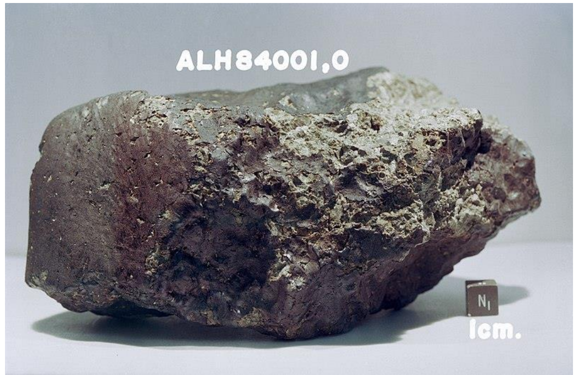
Kuan, A.T., Phelps, J.S., Thomas, L.A. *et al. Nat Neurosci* **23**, 1637–1643 (2020)

Study of the degradation of paintings



Monico et al, Science Advances, 2020

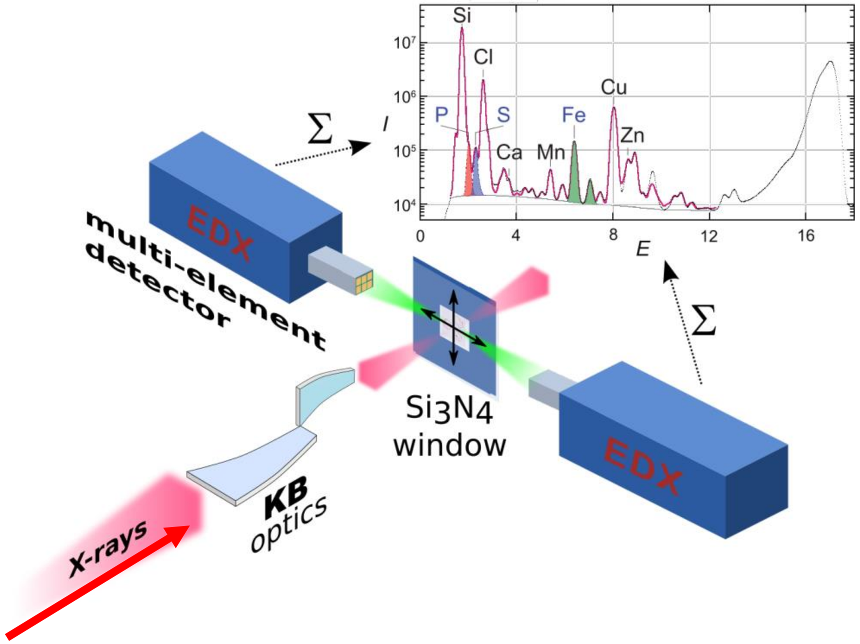
Study of carbonates in meteorite

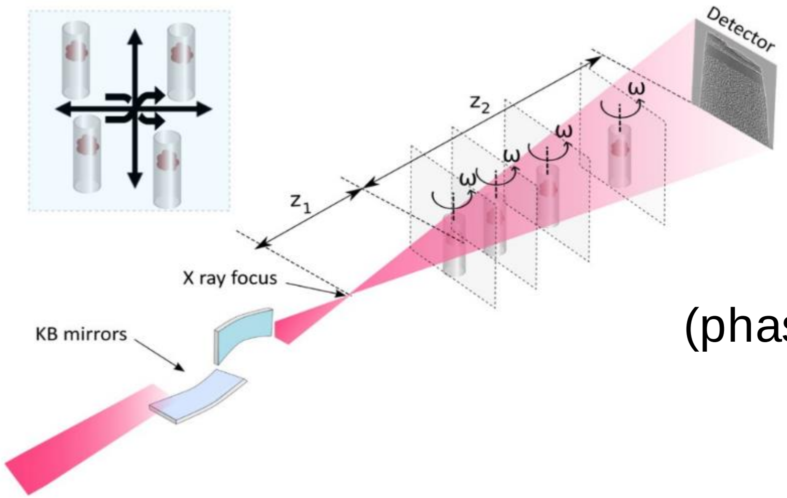


NASA picture

HOW DO YOU DO THAT ?

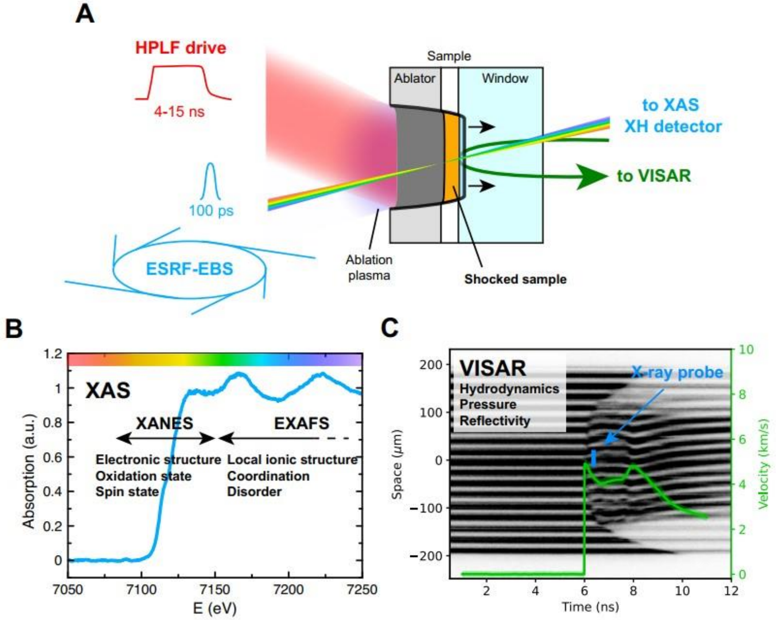
X-ray Fluorescence Microscopy (2D)





Imaging

(phase contrast) tomography

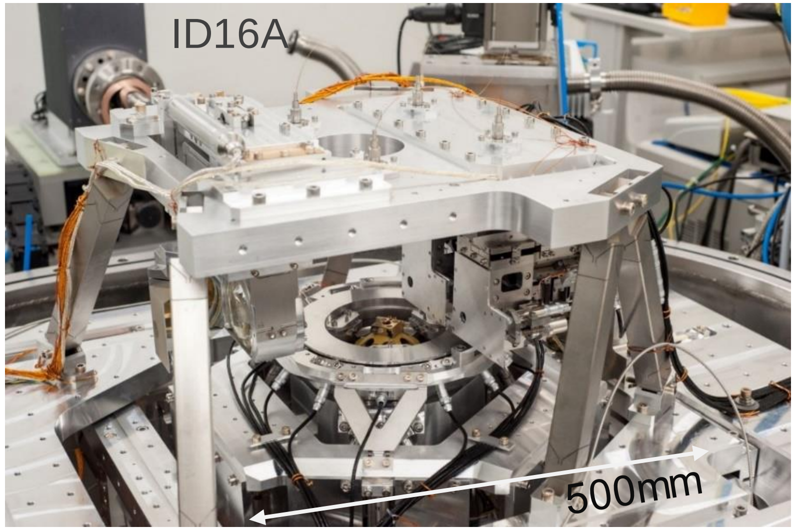


X-ray absorption spectroscopy

LASER compression

High T ~5000 K
High P ~400 GPa

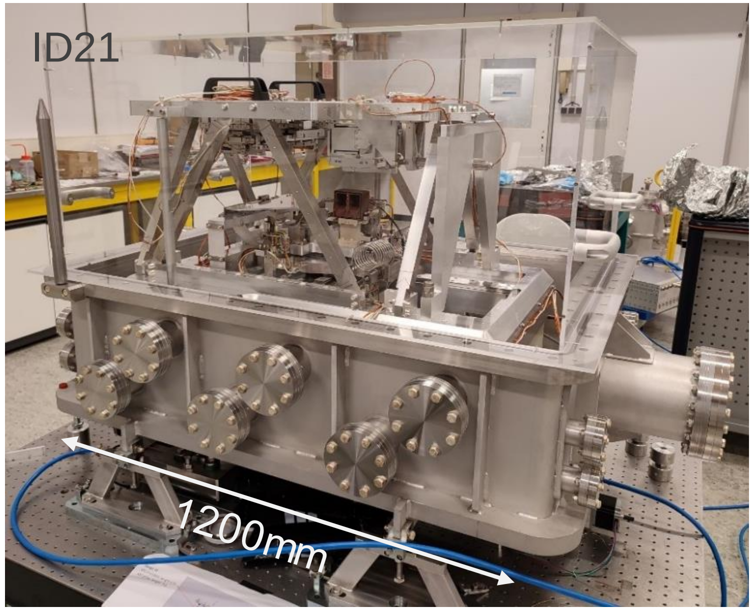
WHAT DOES IT LOOKS LIKE ?



Tomography

2D Scanning

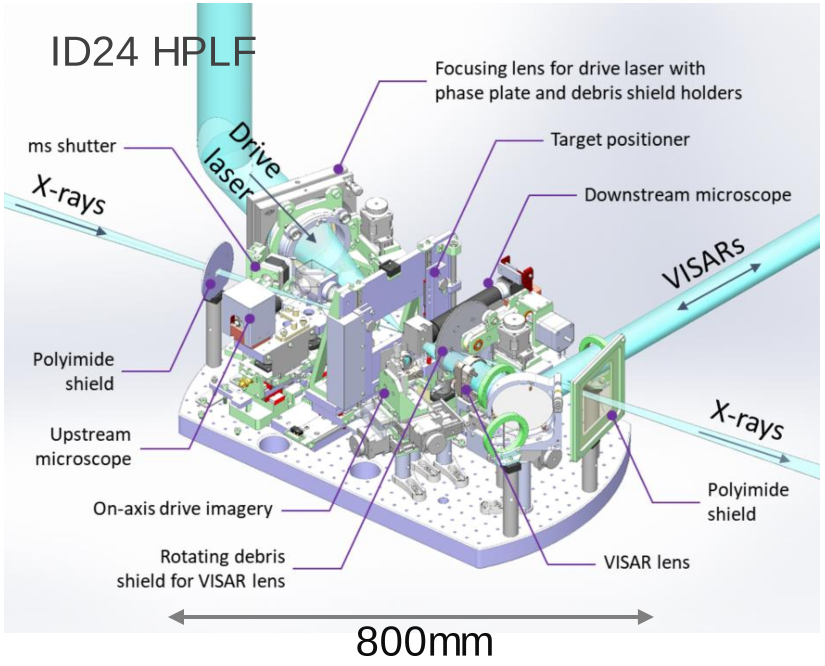
Focus spot size <30nm



2D scanning : step size of 50nm over a 50µm x 50µm zone

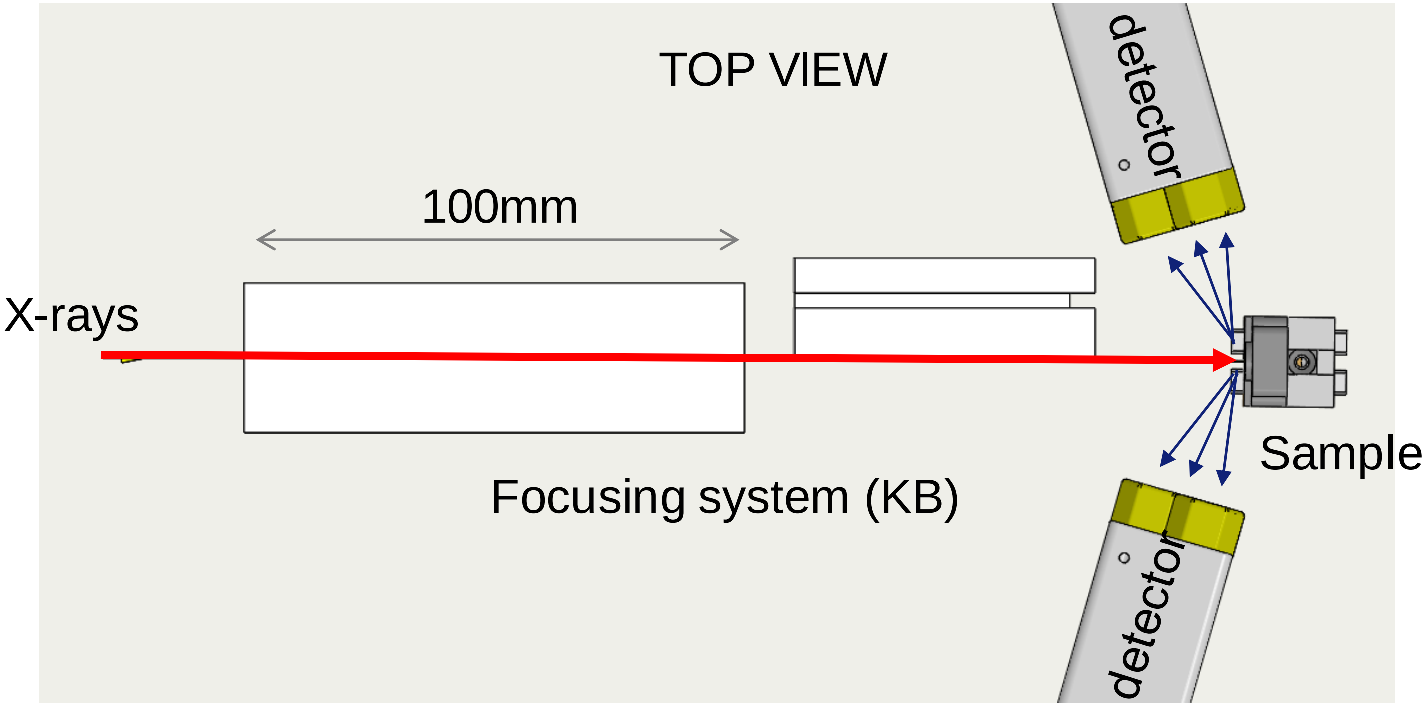
Focus spot ~100nm

Vacuum (10^{-7} mbar)
Cryogenic condition (sample ~110K)



Laser shock to achieve
High pressure (few Mbar)
High temperature (few 1000K)

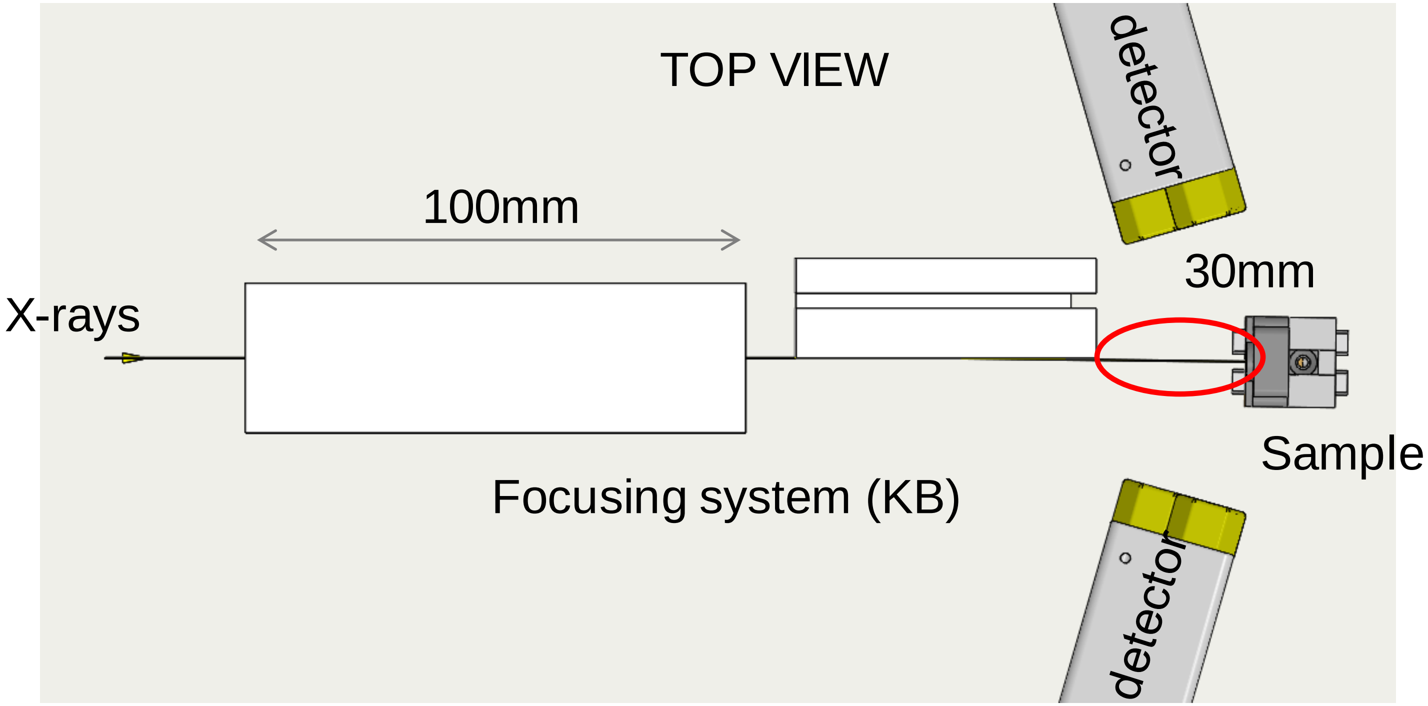
EXPERIMENTAL STATION



CHALLENGES

Between the KB and the sample:
- videomicroscope
- I0 diode
- Pinholes.

(+ stages)



CHALLENGES

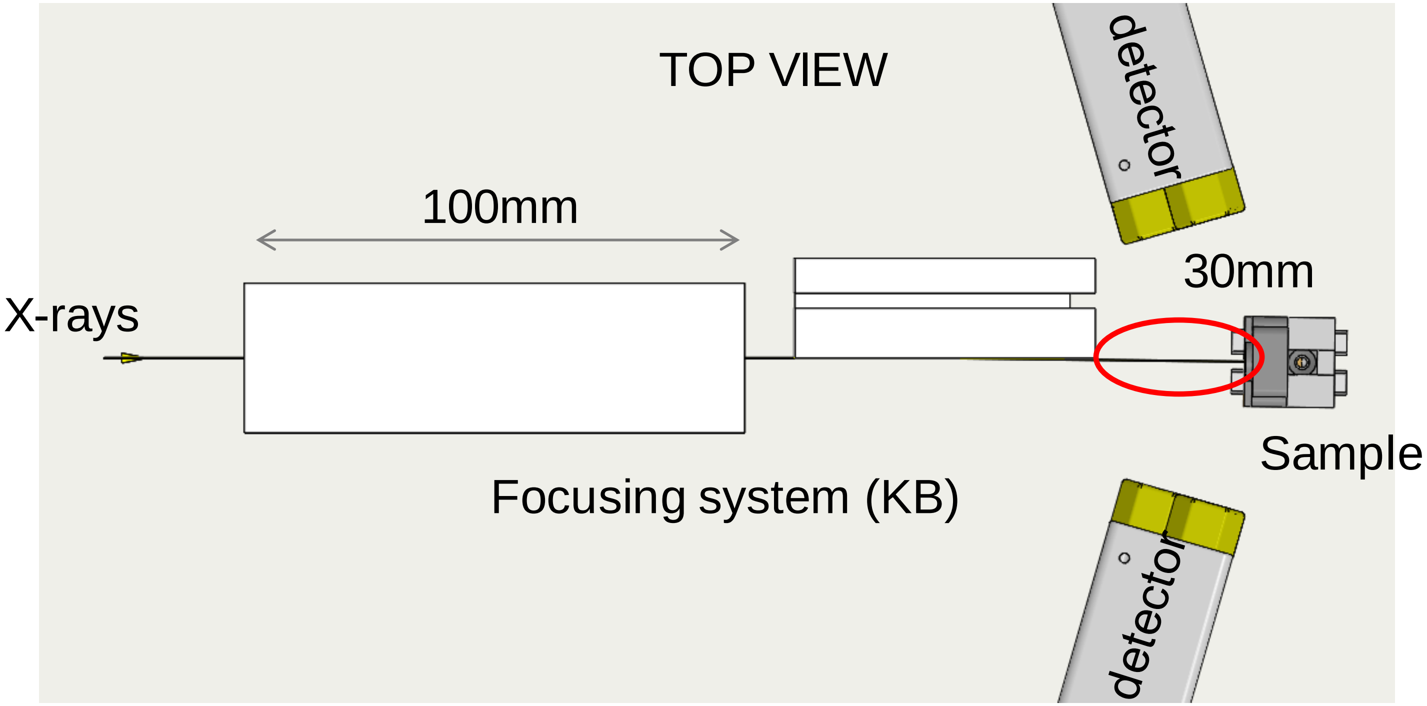
Between the KB and the sample:

- videomicroscope
- I0 diode
- Pinholes.

(+ stages)

- Sample stage fine + coarse
- 2 x KB mechanic + stage

- Cooling system (~100K) : radiation damage
- Vacuum enclosure (10^{-7} mbar)



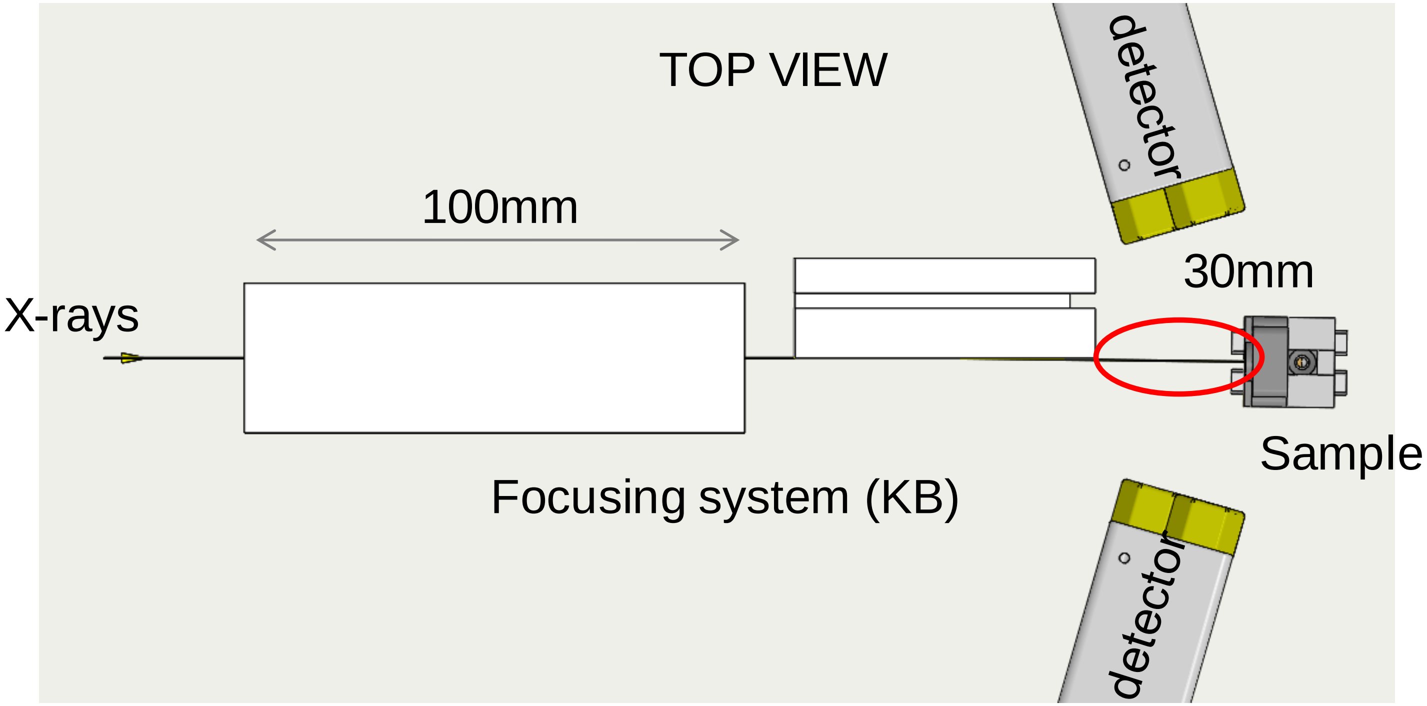
CHALLENGES

Between the KB and the sample:
- videomicroscope
- I0 diode
- Pinholes.

(+ stages)

- Sample stage fine + coarse
- 2 x KB mechanic + stage

- Cooling system (~100K) : radiation damage
- Vacuum enclosure (10^{-7} mbar)



→ SEVERE SPACE CONSTRAINTS ←

→ STABILITY REQUIREMENTS : 20 to 50nm KB / sample ←

SPACE CONSTRAINTS

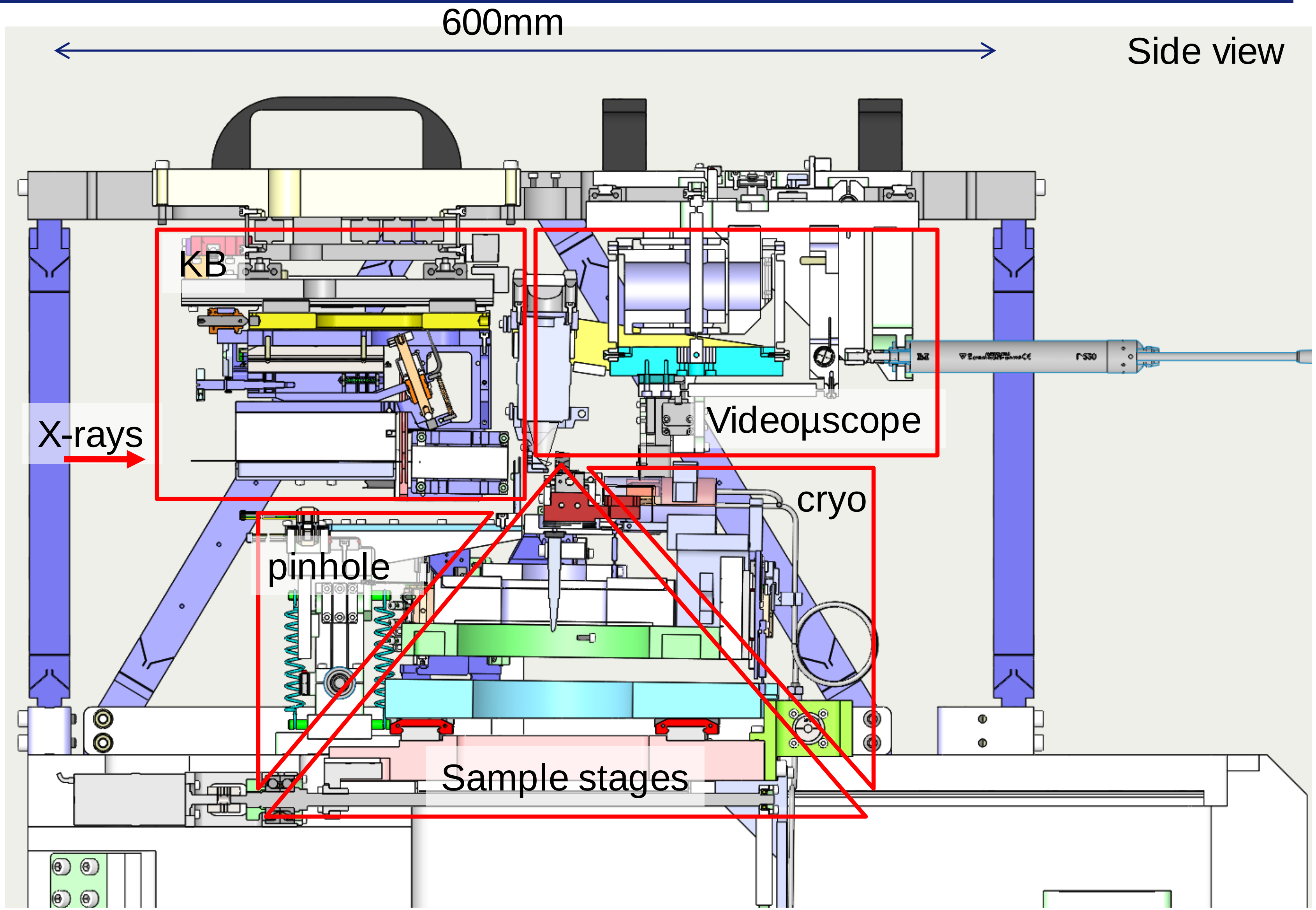
X-ray optic (KB)

Videomicroscope

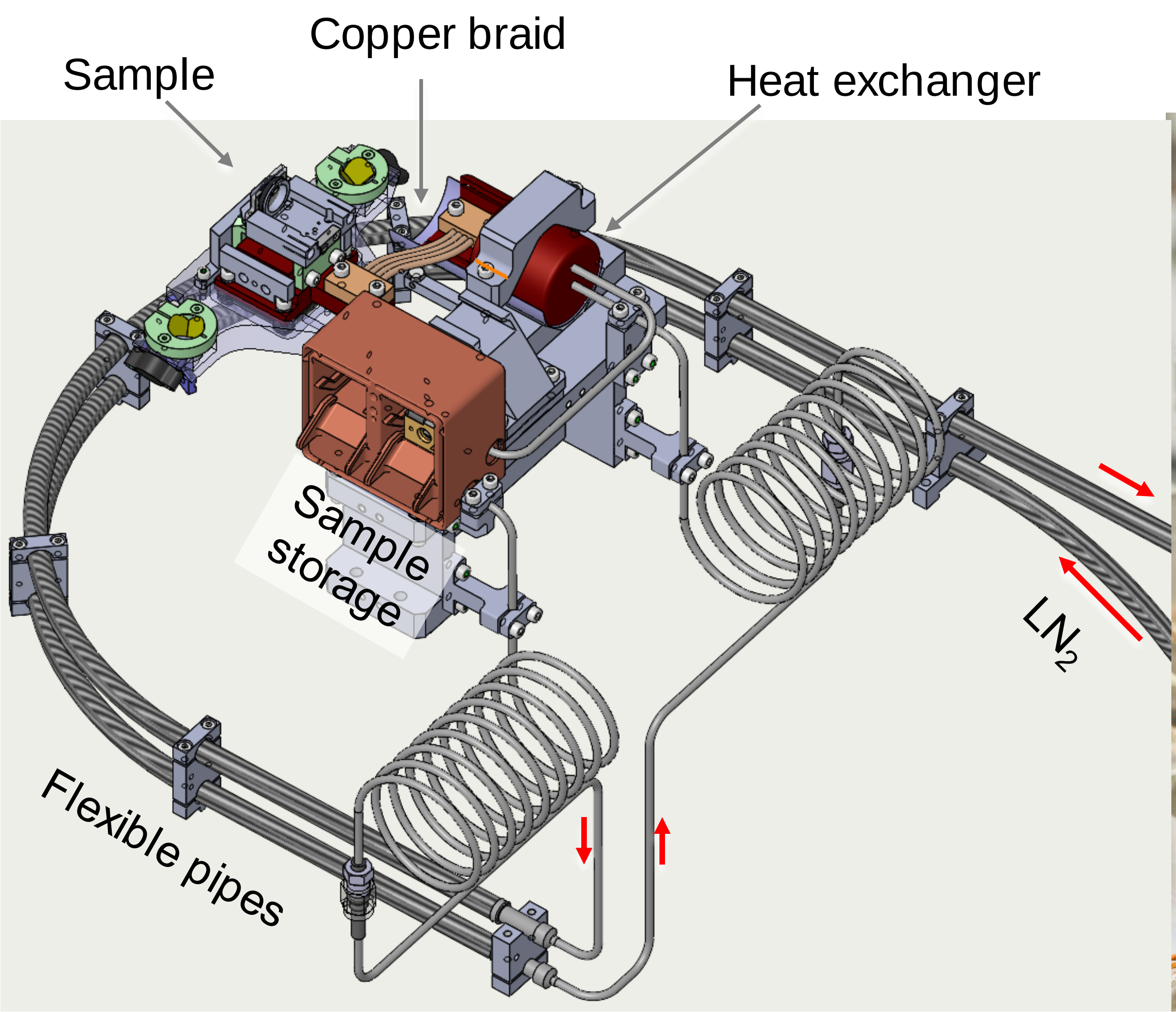
Pinhole and diode

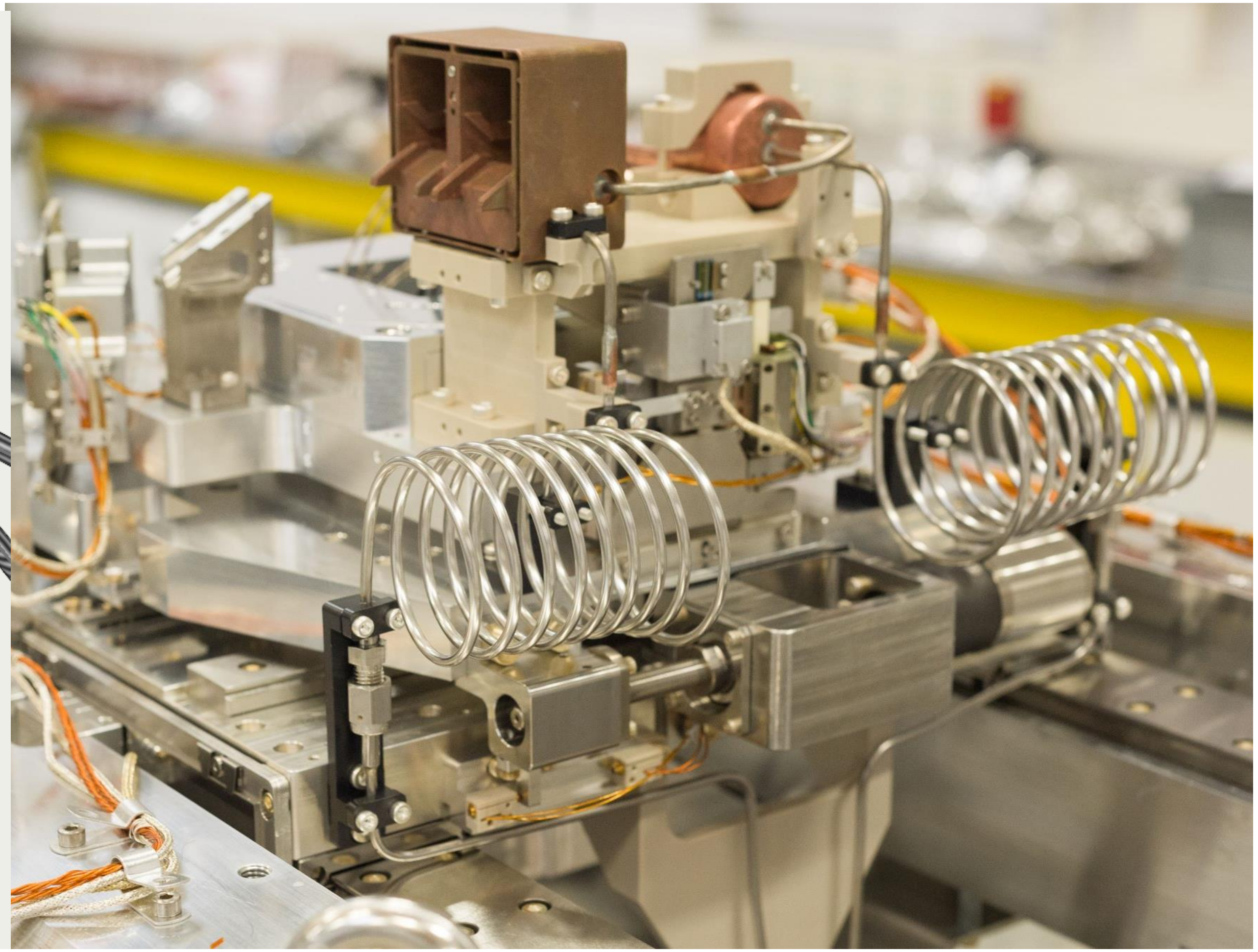
Cryo loop

Sample



CRYO COOLING SYSTEM

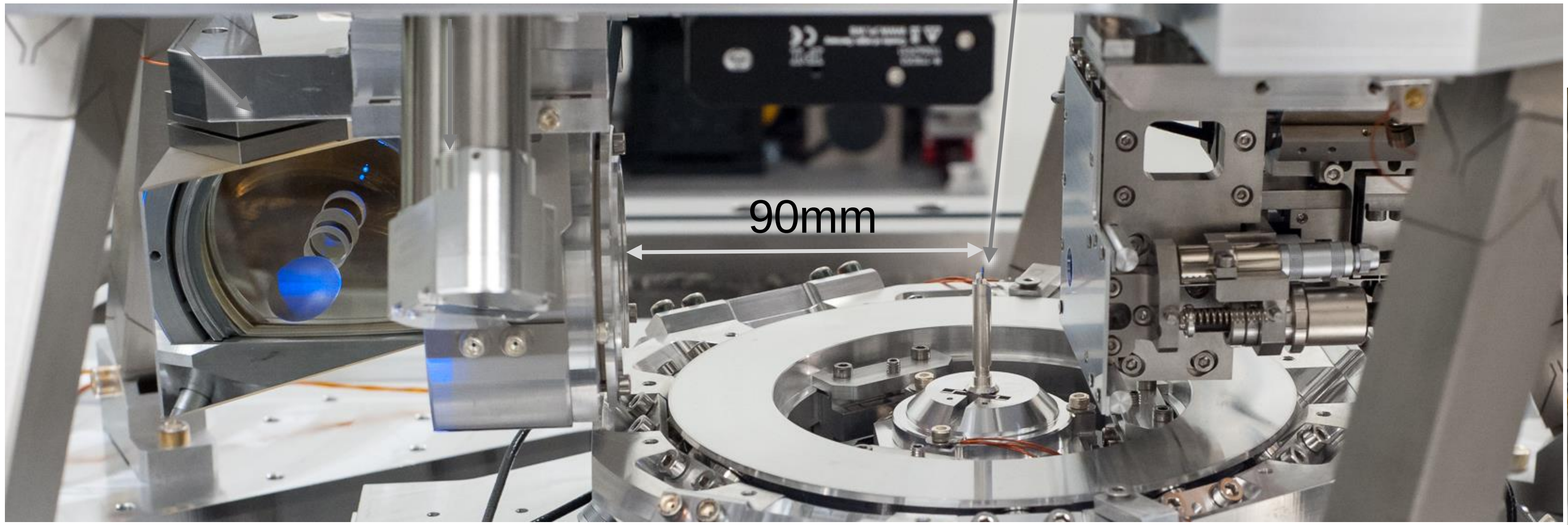


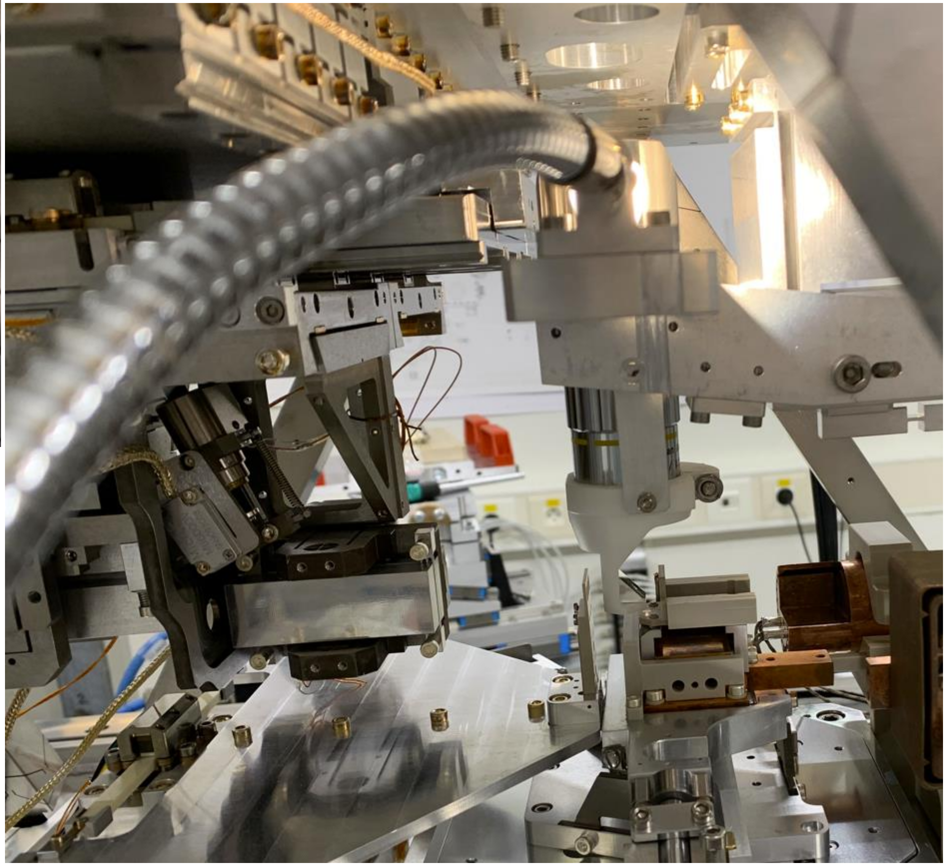


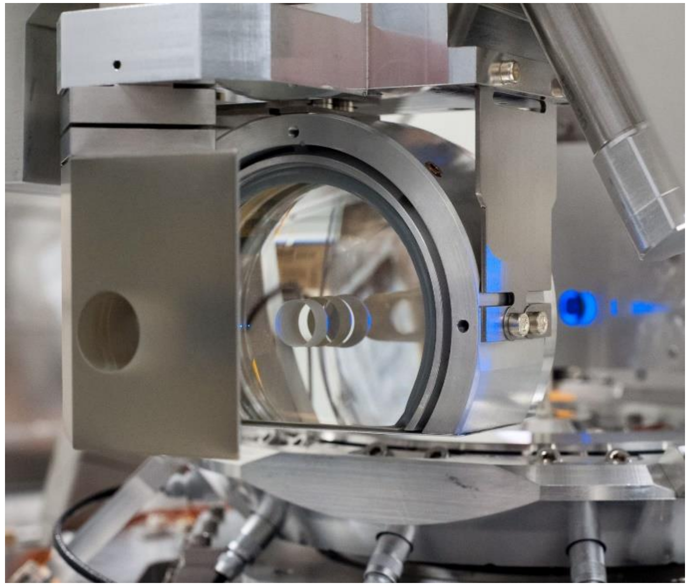
VIDEOMICROSCOPE

Folding mirror

Sample

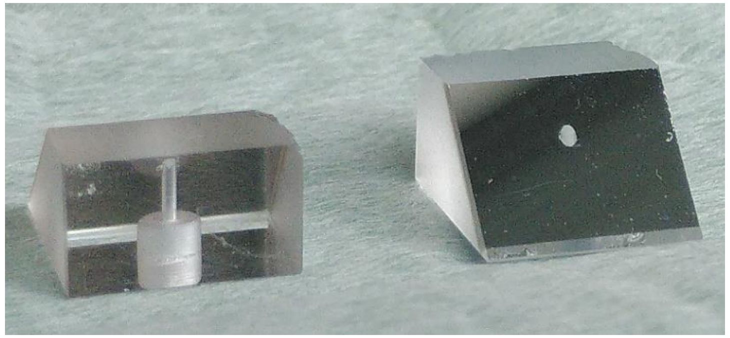






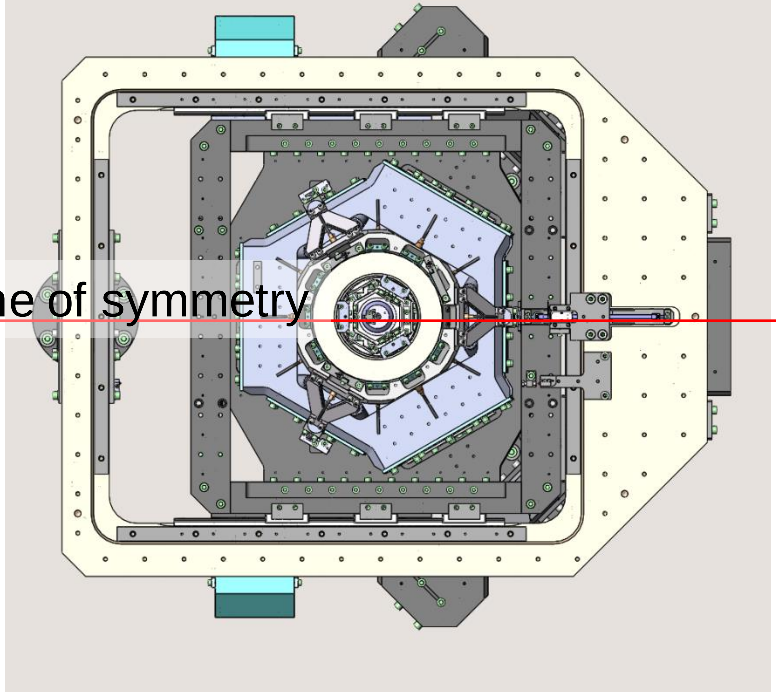
Long working distance
Drilled optic

field of view ~mm resolution ~µm

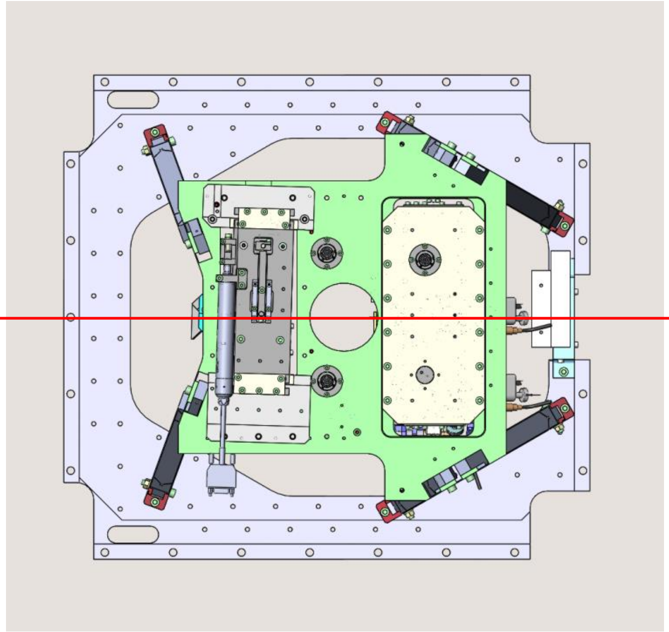


THERMAL DESIGN : SYMMETRY

SAMPLE STAGE

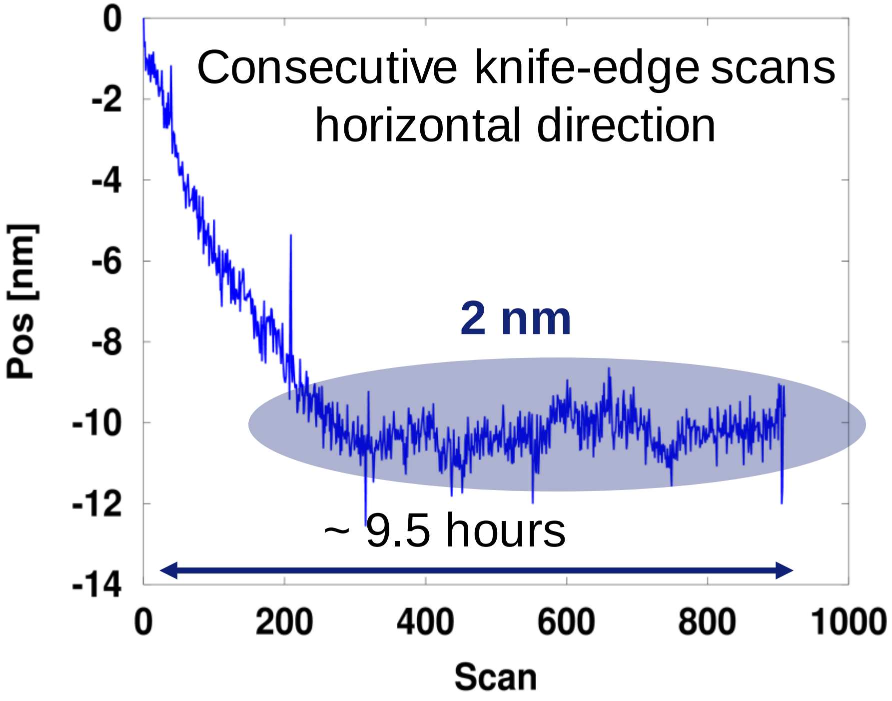


KB STAGE



Plane of symmetry

X-Rays



Left/right symmetry

Heat load / Forces / Geometry

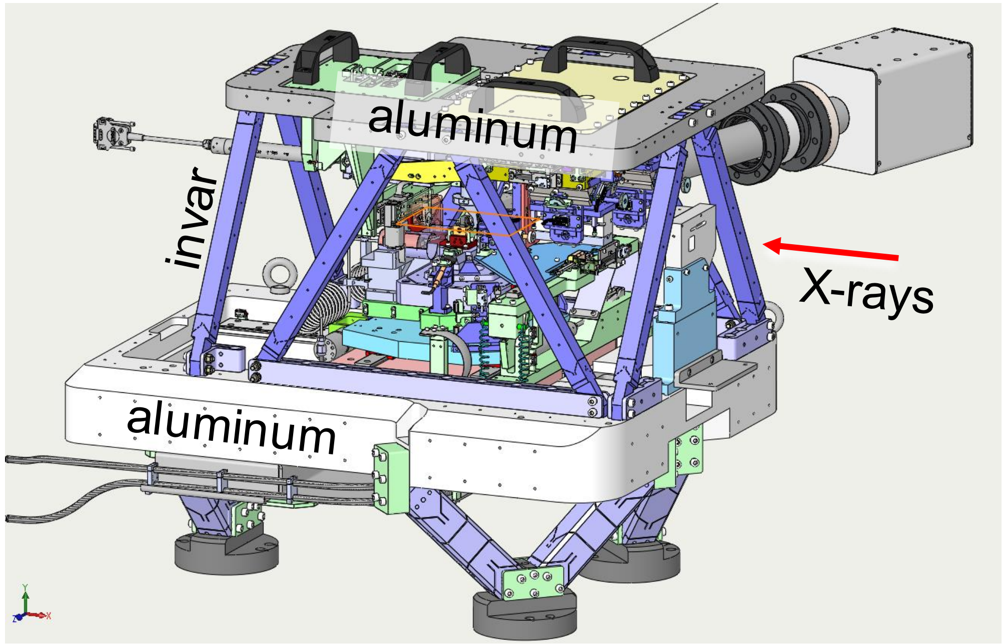
Reduce the effect of the temperature change on the geometry of the station

Material used

Aluminum alloy mainly
(High thermal conductivity, light, machinability)
→ Limitation of thermal gradients
→ Transient period shorter

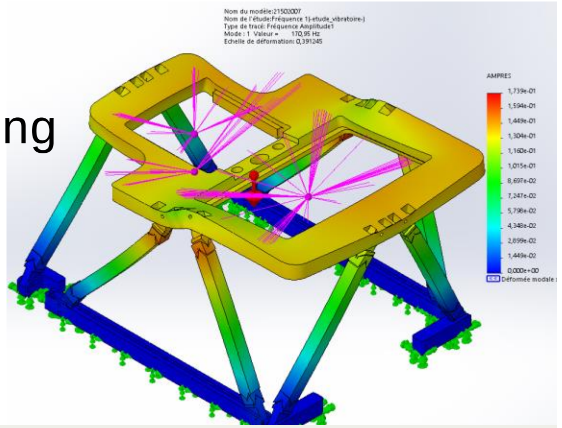
High thermal expansion is managed by symmetry

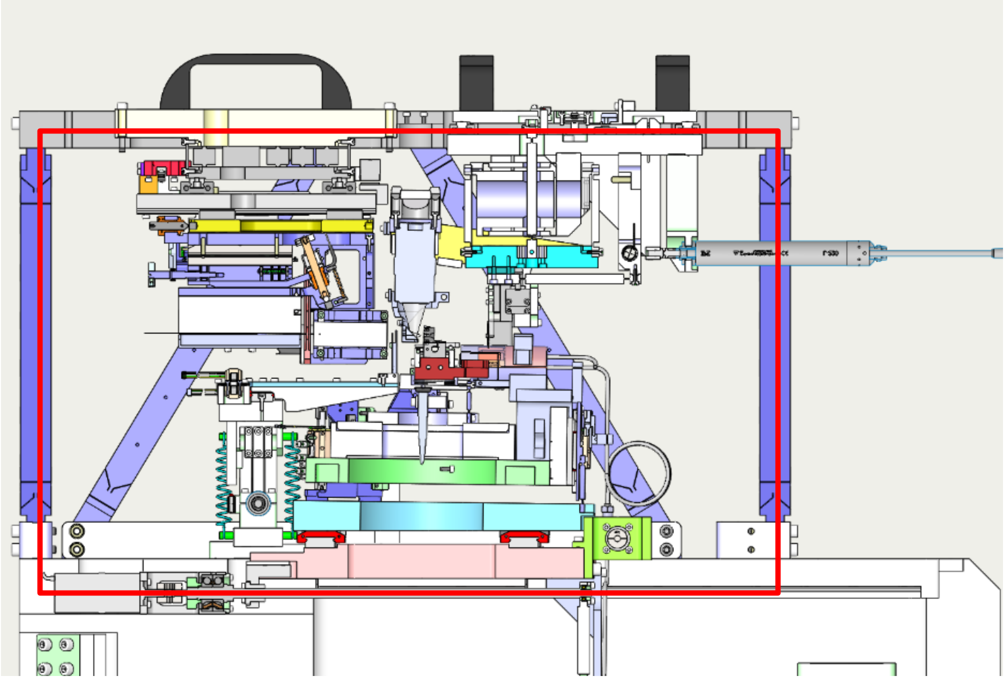
Invar where a symmetric geometry is impractical



Closed frames

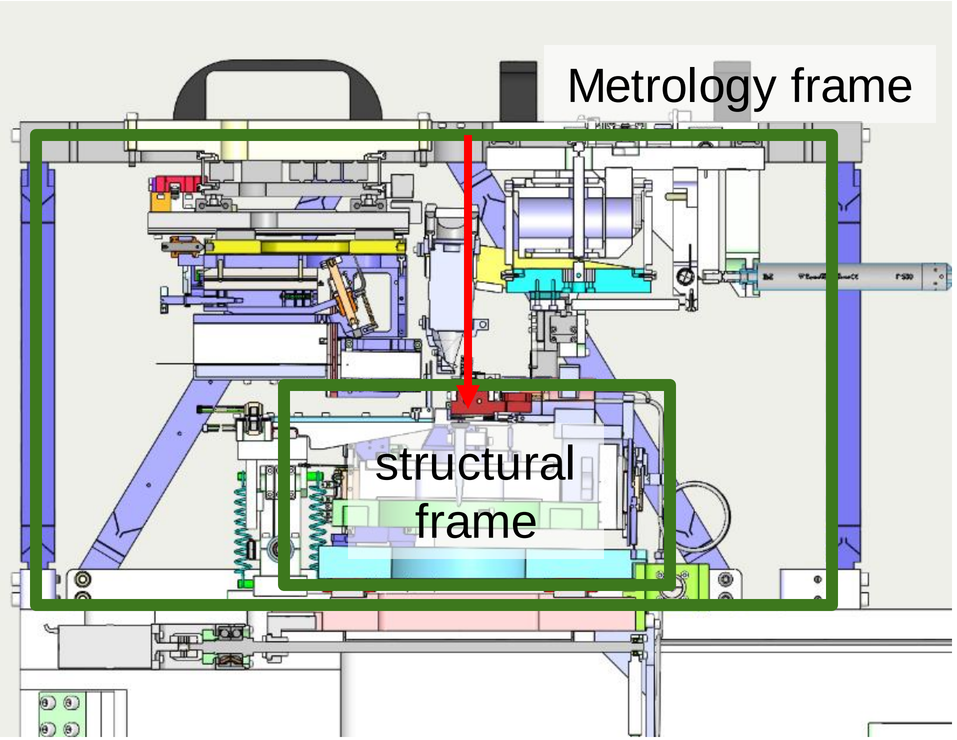
Less sensitive to thermal bending
Stiffer than open ones

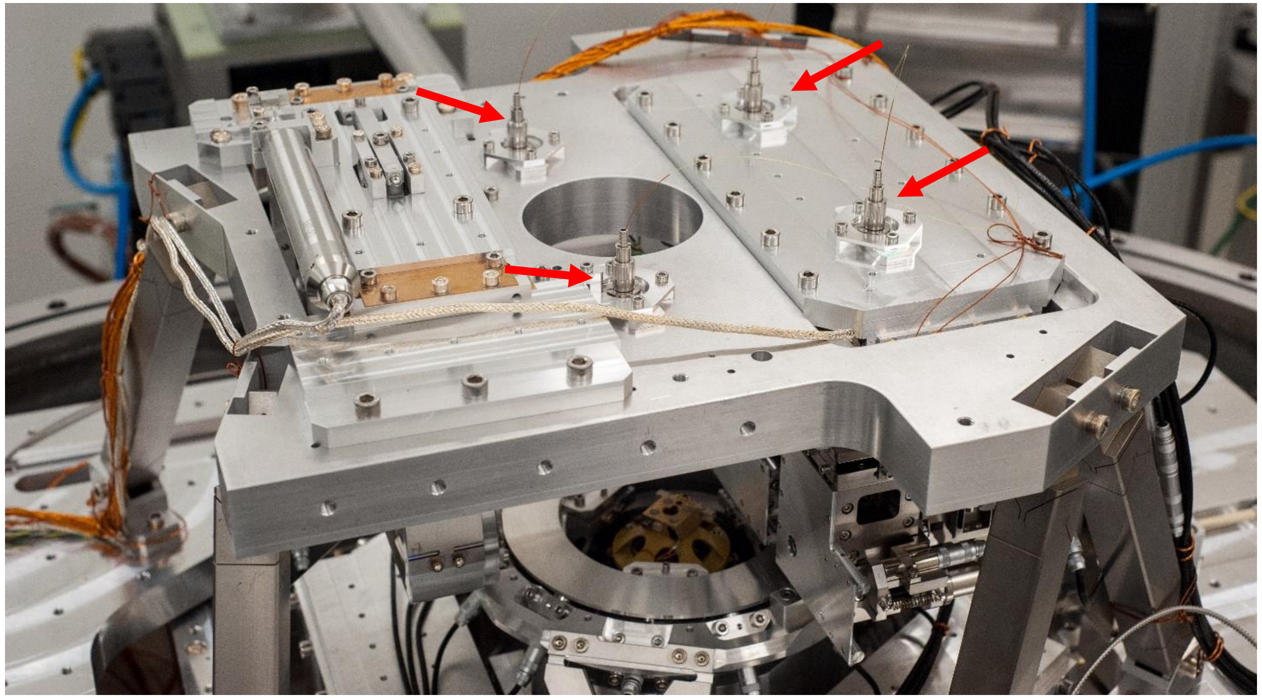


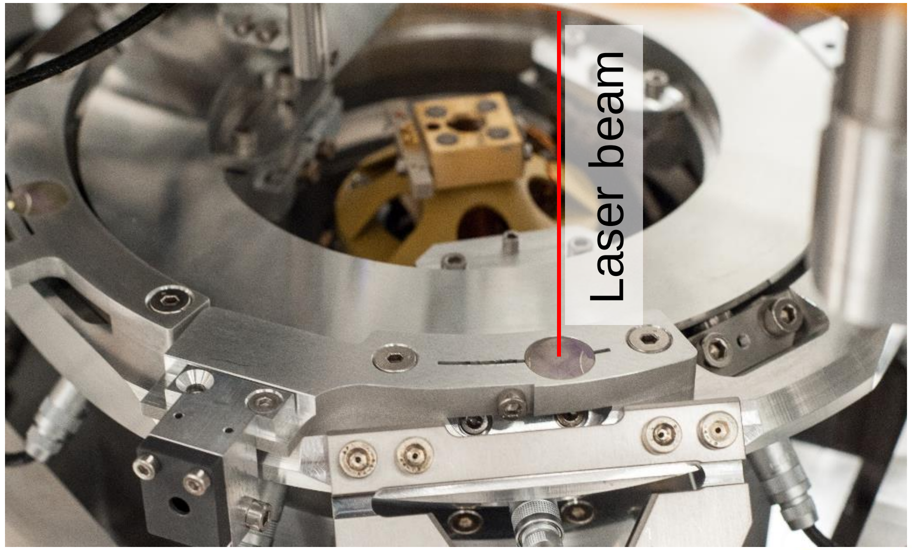


SPECIFIC METROLOGY FRAME

Separation of the metrology frame from the structural frame



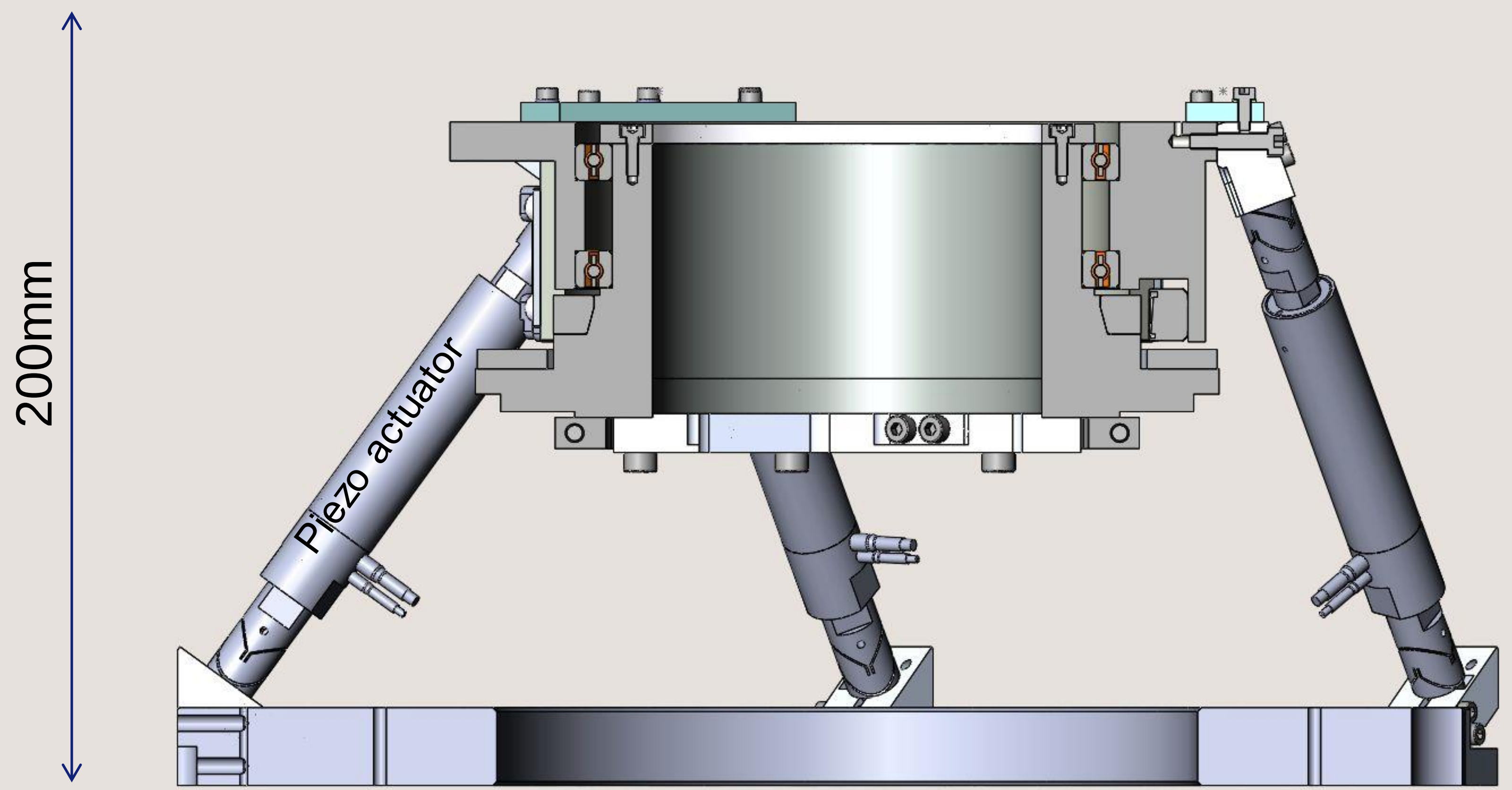




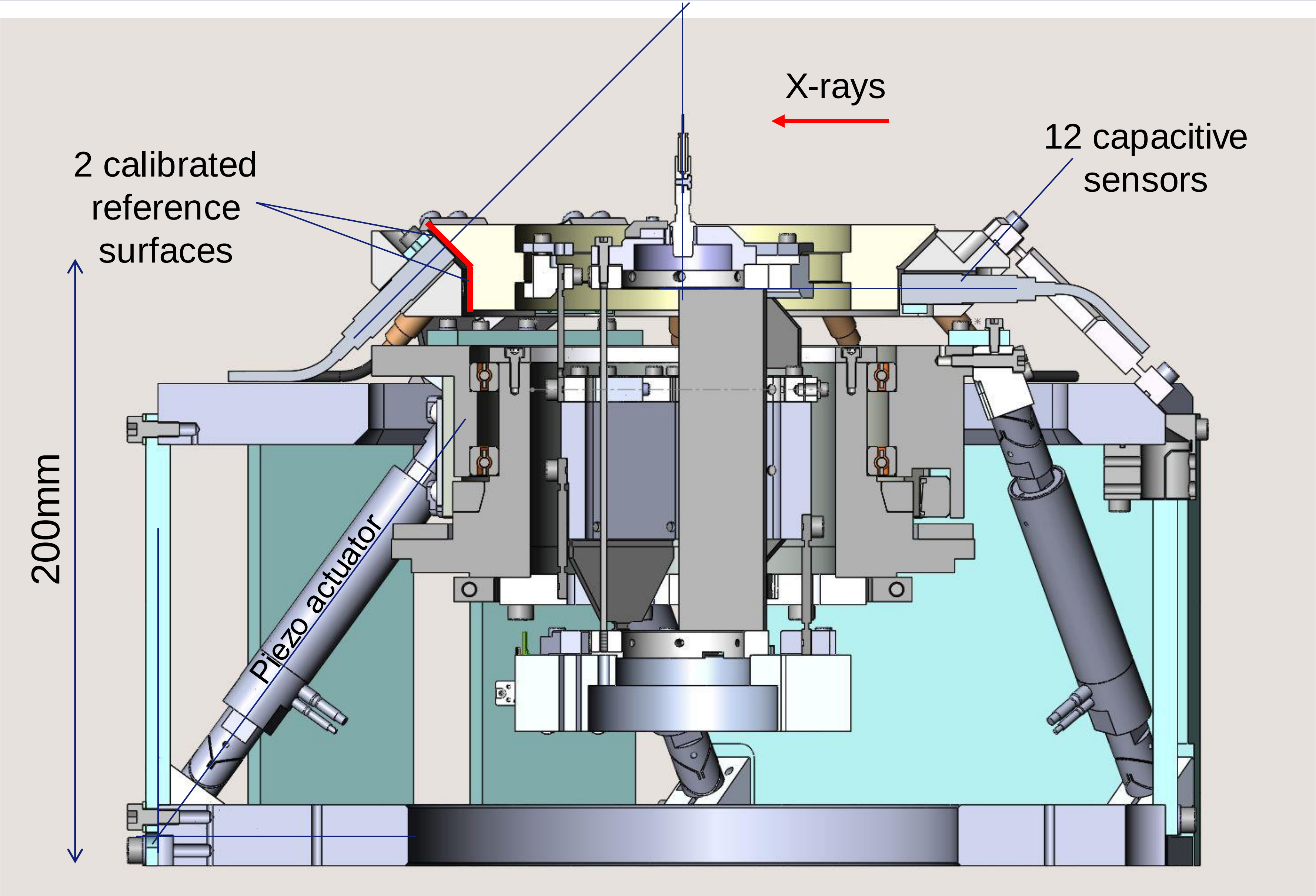
Limits the effect of the perturbations acting on the structural frame (thermal deformation, parasitic forces…)

ID16A TOMOGRAPHY

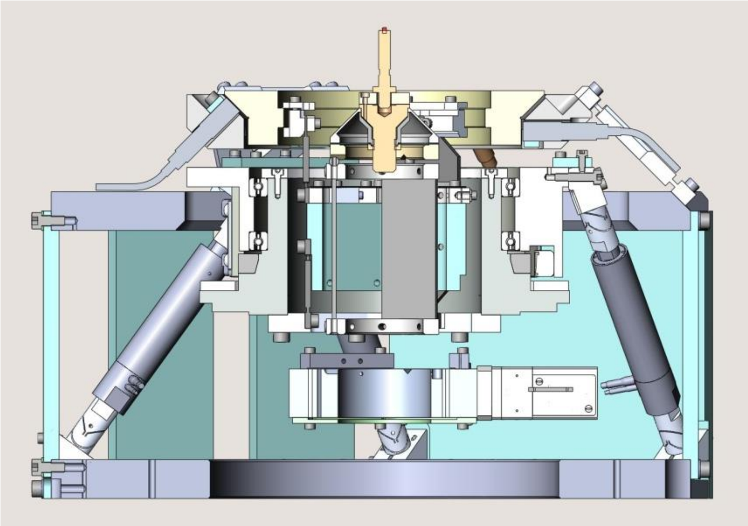
Spec : run-out<50nm and vacuum



ID16A TOMOGRAPHY



REAL-TIME HEXAPOD CONTROL



12 capacitive sensors + electronic

0…10V (0…100µm)

12 AD converters,16 bits
10 000 samples /s

$\{M_i(\theta_j)\}$

average

$\{M_i(\theta_0)\}$

CONTROLLER

$\times[S']$

$\times -[H]$

6 piezo-actuators amplifiers / controllers in **closed** loop

0…10V (0…60µm)

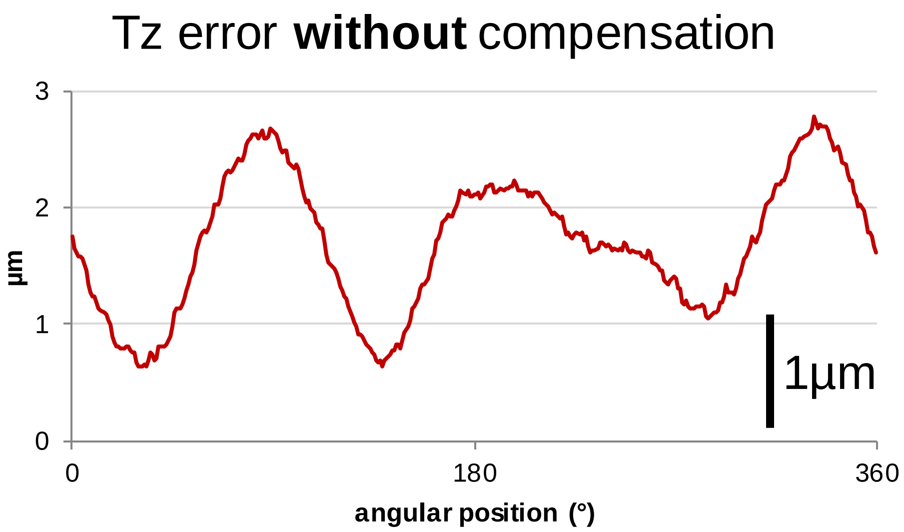
6 DA converters
18 bits

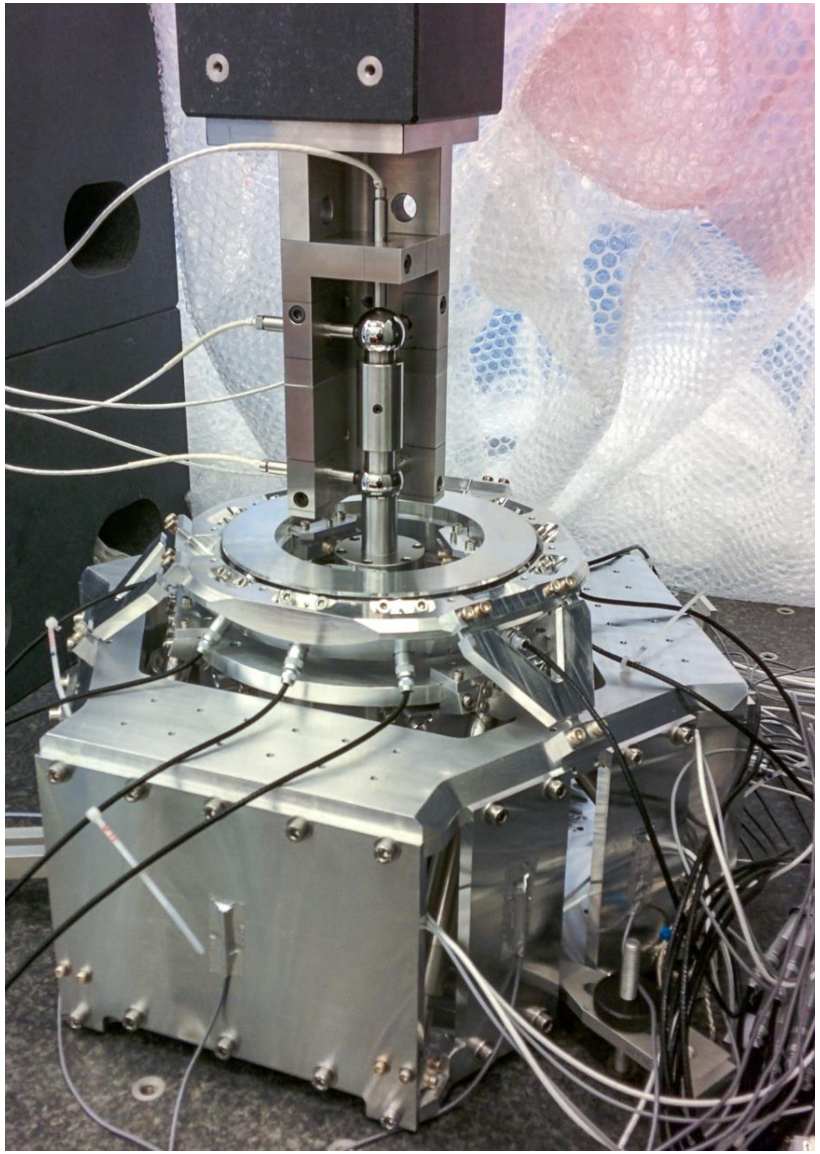
Rotation encoder → Angular position θ_j → interpolate shape and concentricity errors

$$\begin{Bmatrix} T_x = 0 \\ T_y = 0 \\ T_z = 0 \end{Bmatrix} \begin{Bmatrix} R_x = 0 \\ R_y = 0 \\ R_z = 0 \end{Bmatrix}$$

Set points of the sample movements

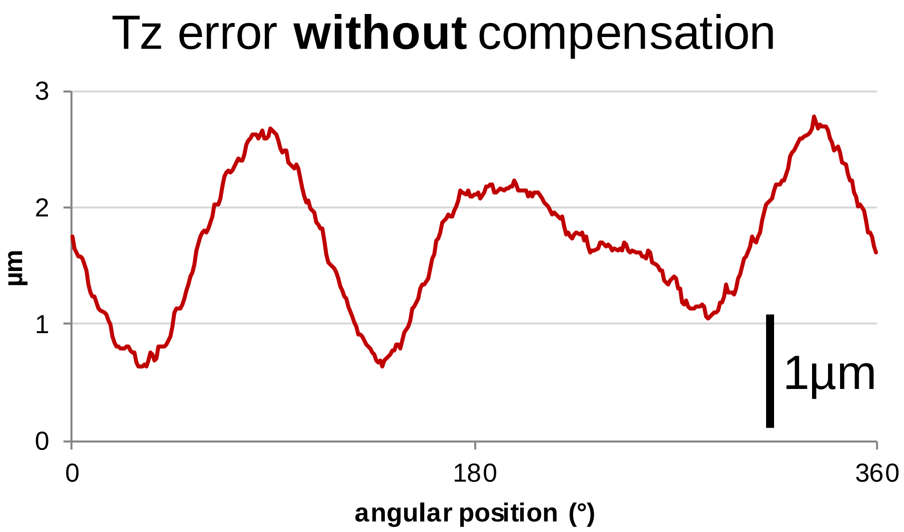
ROTATION STAGE ERROR COMPENSATION

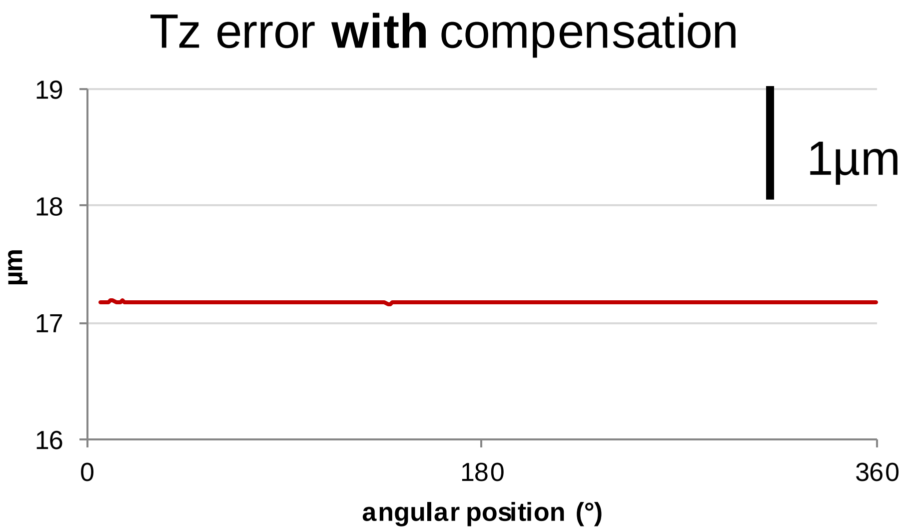


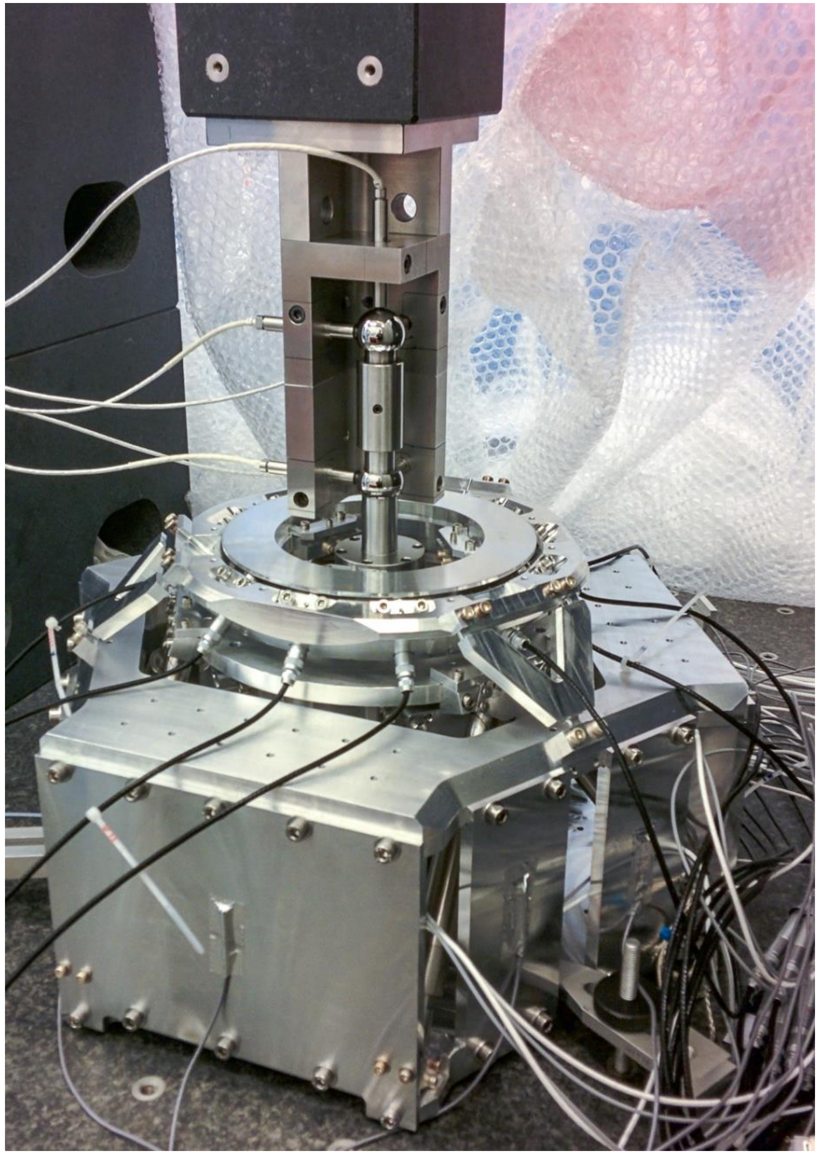


L Ducotté

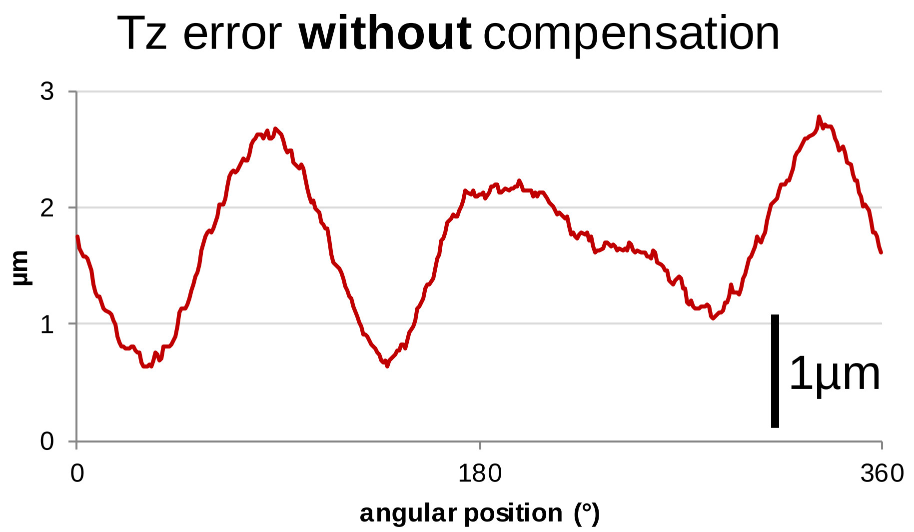
ROTATION STAGE ERROR COMPENSATION

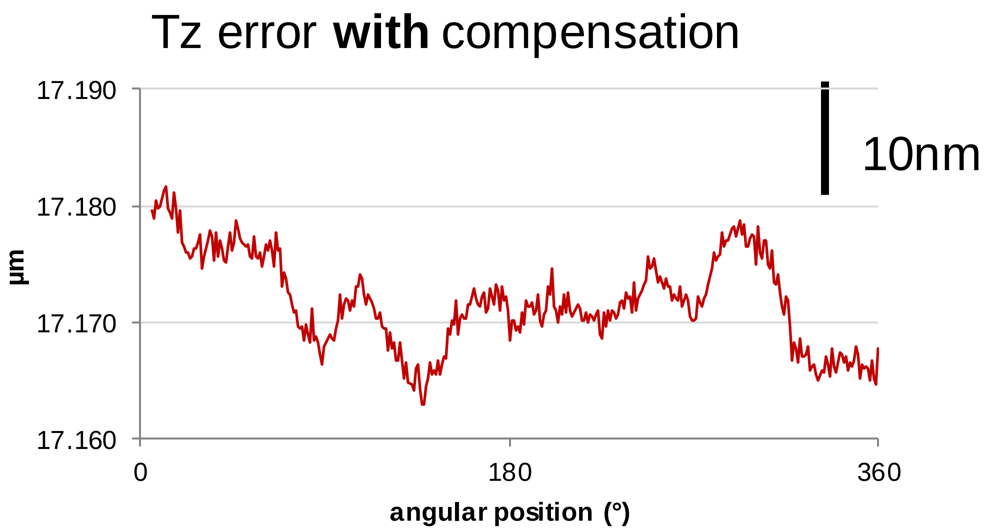


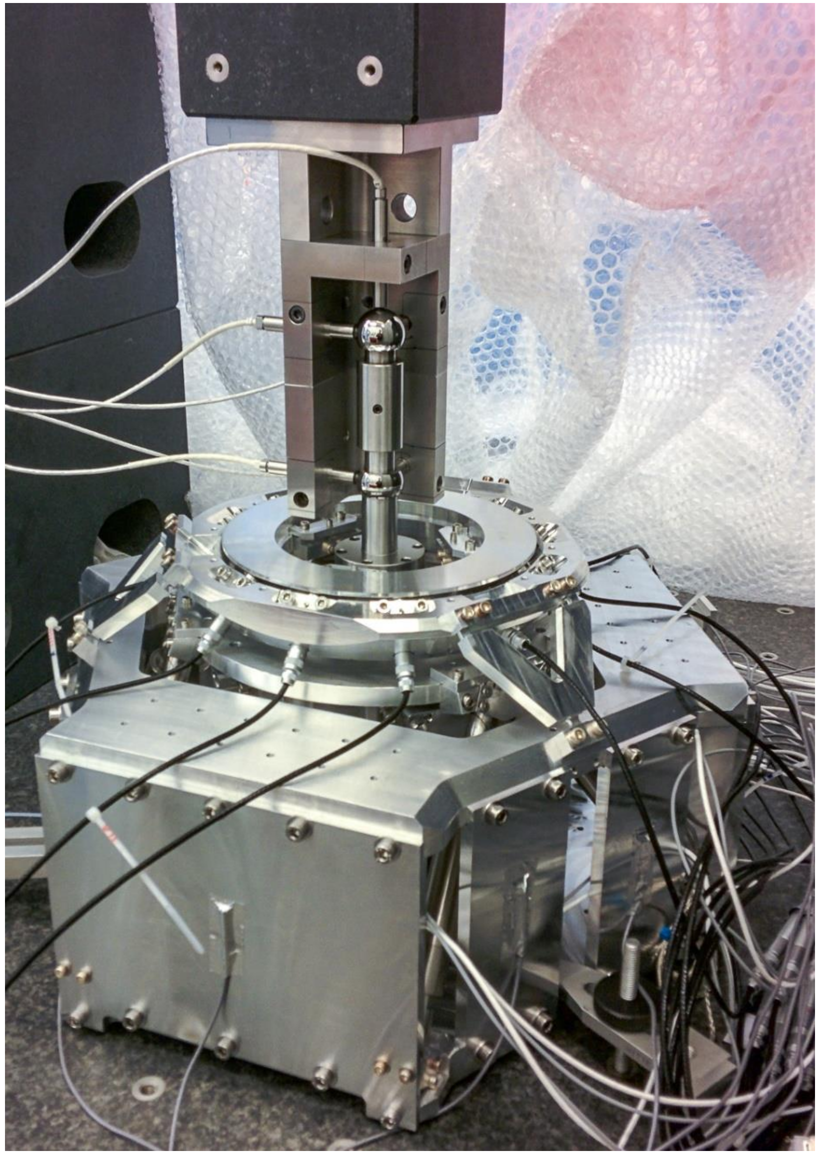




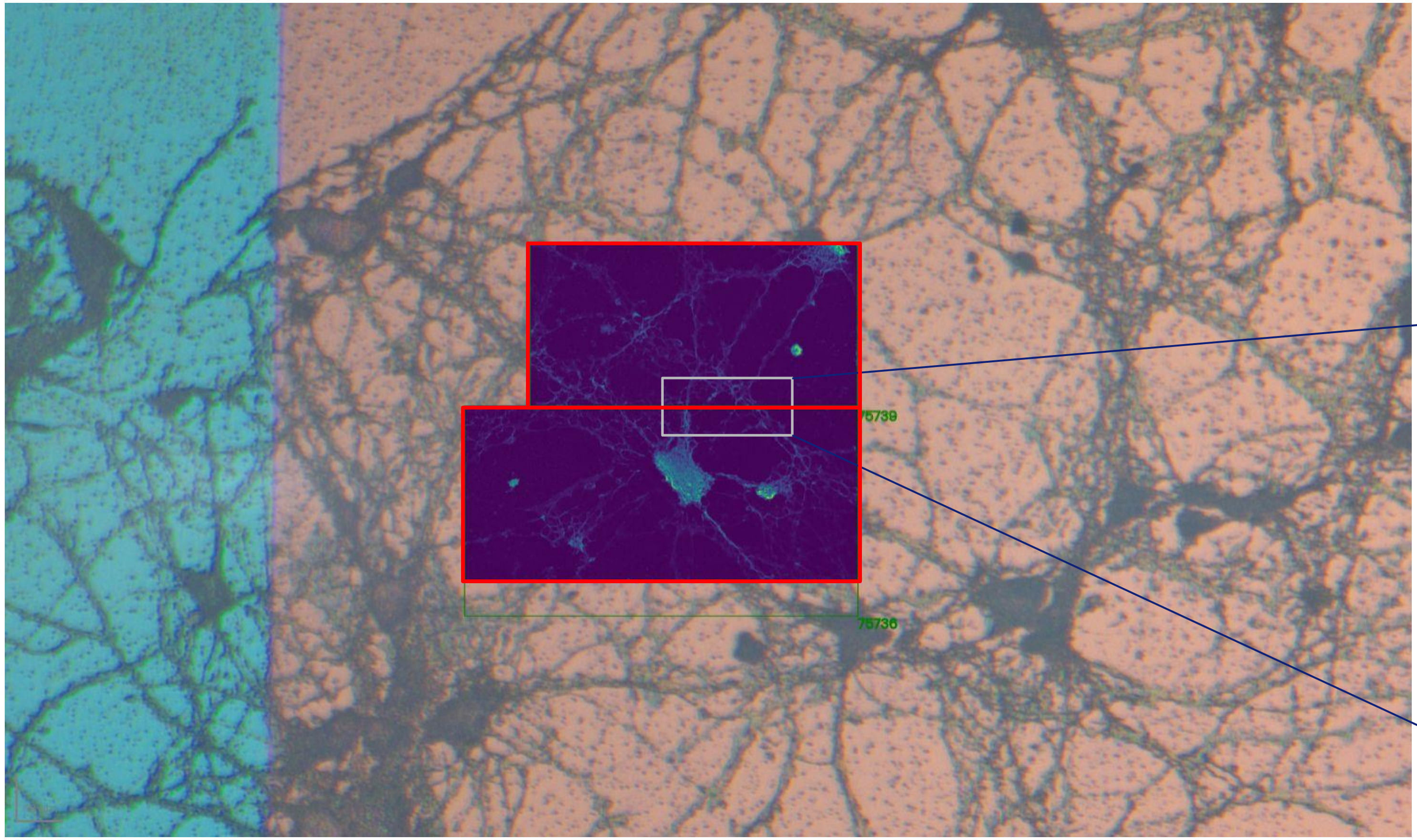
ROTATION STAGE ERROR COMPENSATION







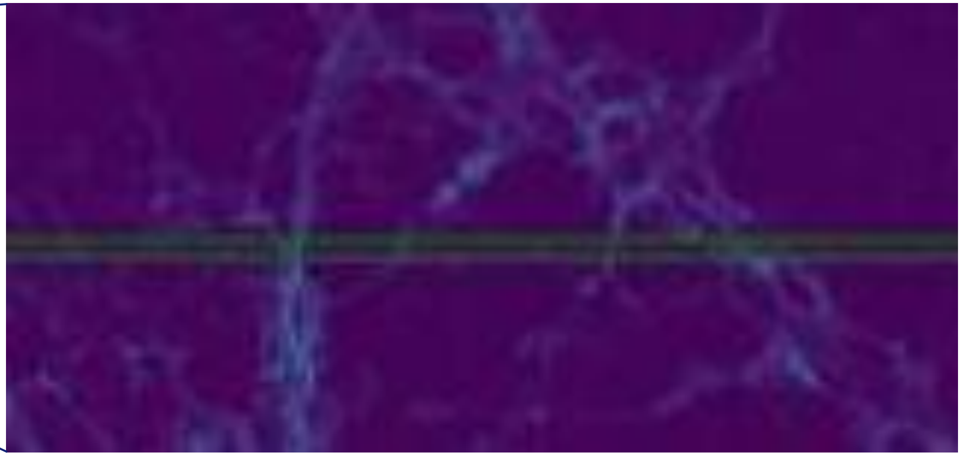
ID21 FIRST RESULTS



X-Ray fluorescence maps of potassium distribution in cells

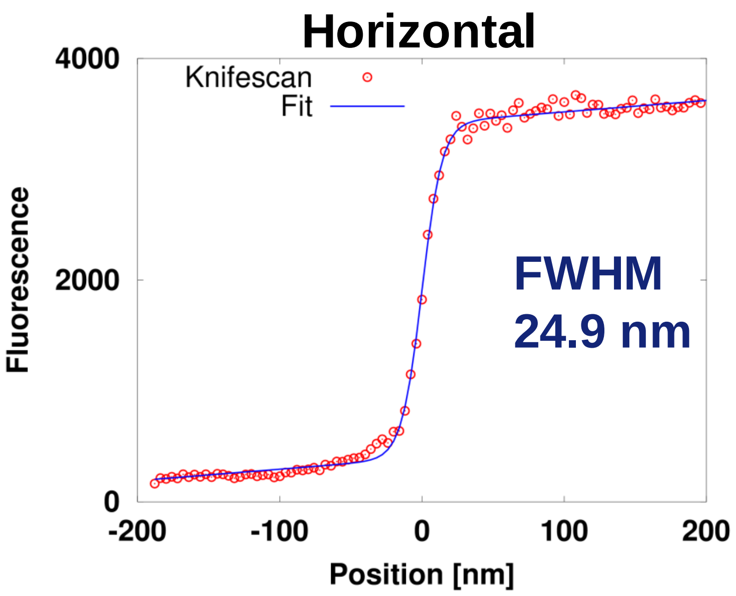
2 maps of about 40µm x 20µm 5 hours apart

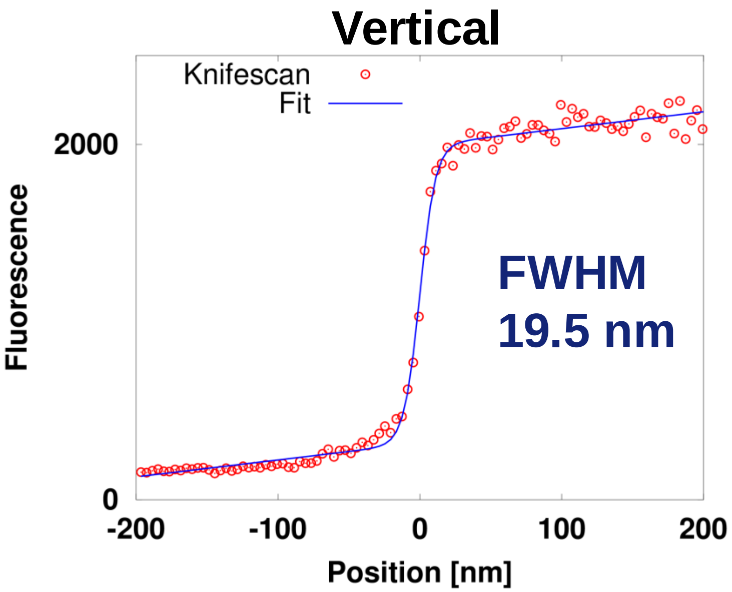
100nm step size



A. Carmona, R. Ortega et al.
Chemical Imaging and Speciation - LP2i – UMR5797 – CNRS - University of Bordeaux
Aiyarin Kittilukkana and Chalermchai Pilapong
Department of Radiologic Technology, Faculty of Associated Medical Science, Chiang Mai University, Thailand

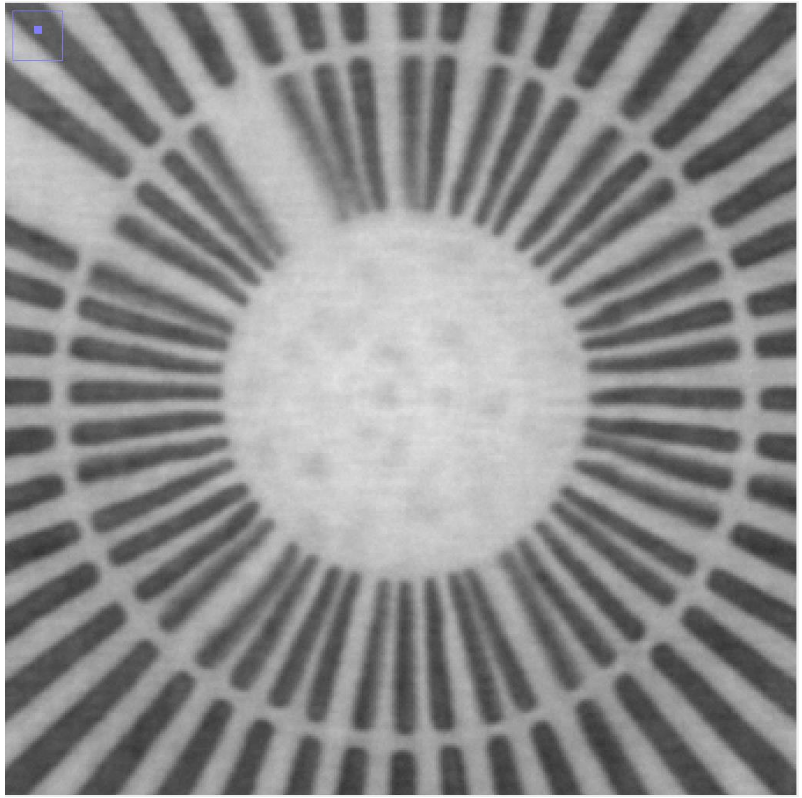
PERFORMANCES OBTAINED AT ID16A





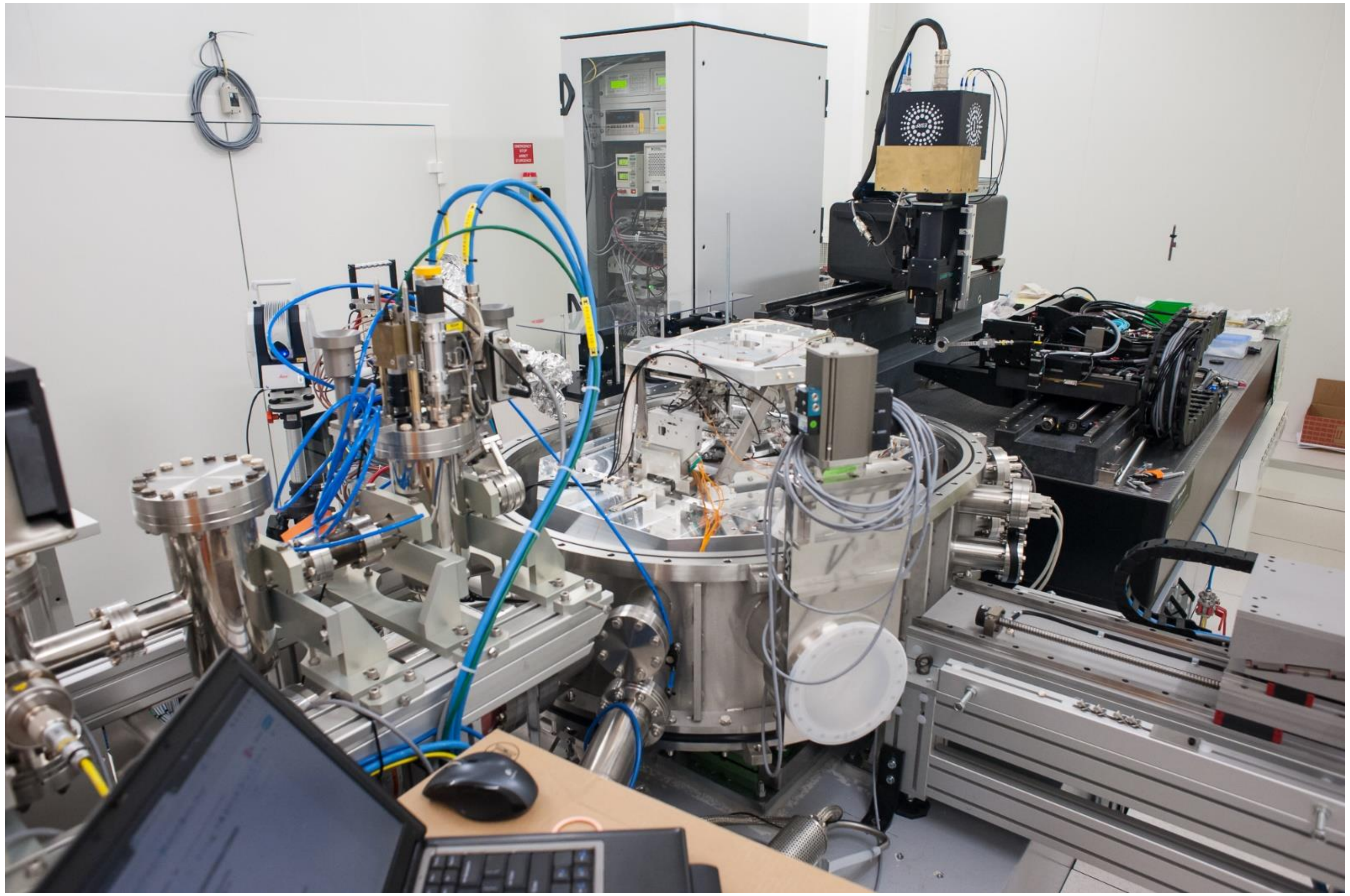
Focus size: 25 x 19 nm (April 2016)

10µm x 10µm
Step size 10nm
(April 2024)



SUMMARY

- Experimental stations can be very diverse
- No space available : creativity and compromise
- Precision achieved 10 to 100nm for some stations



THANK YOU !

<u>ID21 beamline team</u>
Hiram Castillo Michel,
Murielle Salomé,
Marine Cotte,
Gaëtan Goulet

<u>ID16A beamline team</u>
Peter Cloetens,
Alexandra Joita-Pacureanu,
Lionel André
Murielle Salomé,

<u>ISDD</u>
Delphine Baboulin
Philipp Brumund, Bob Baker,
Philippe Tardieu,
Bertrand Pelissier,
Olivier Hignette, Daniel Fiole
Cedric Cohen, Eric Matthieu
Ricardo Hino, Cyril Guilloud
Jens Meyer, Ludovic Ducotté
Thomas Dehaeze

<u>ExpD</u>
David Bugnazet, Yves Watier,
Peter van der Linden,

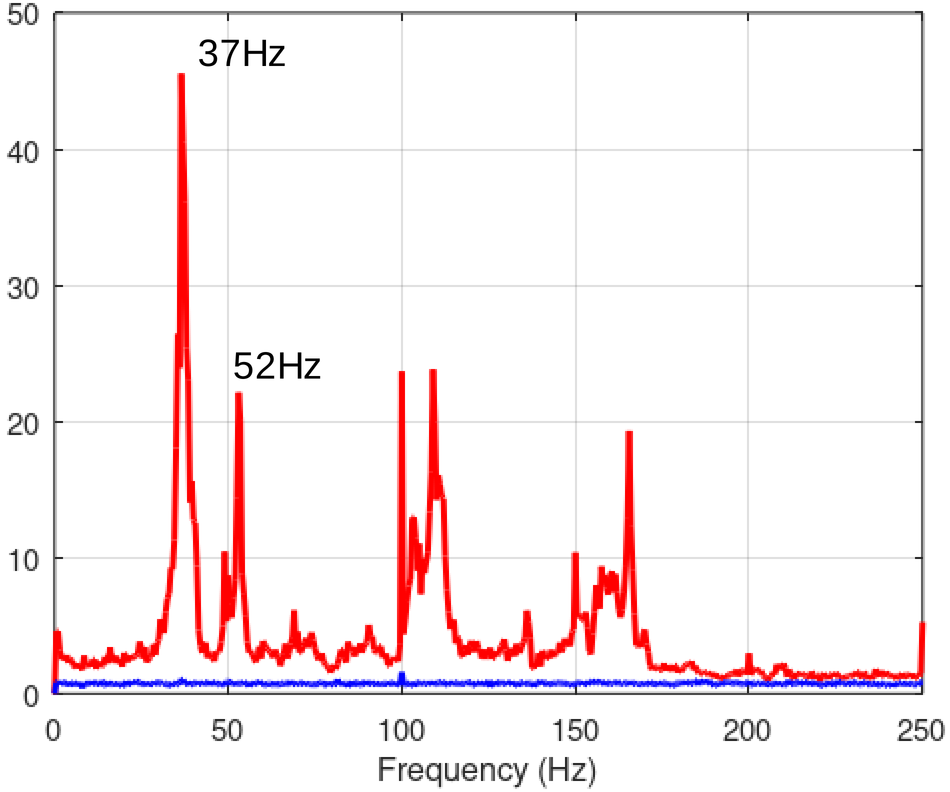
Experimental cabin ID32

Photo © P Jayet

PERSPECTIVES

The ID16A station was designed for step by step scan, it is a “slow” machine

FFT of the fluorescence signal spectrum (horizontal direction)

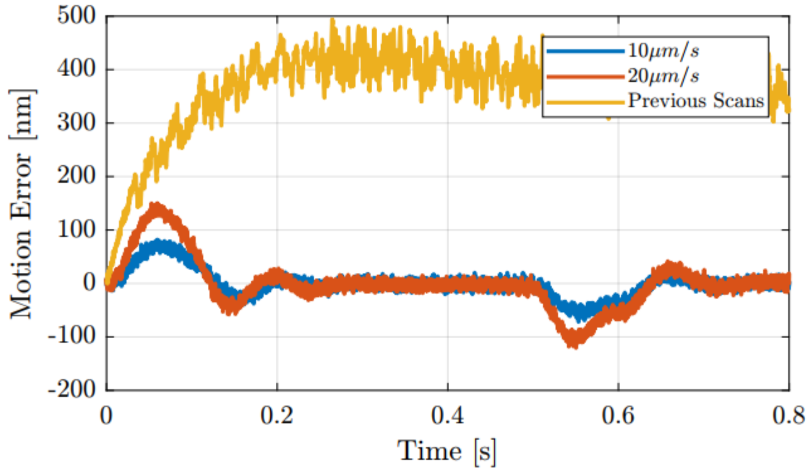


Taking advantage of the increased flux of EBS and improving the performance in terms of precision and **speed** (for continuous scan)

require to take into account perturbations during the design phase

- ground floor vibration,
- sensor noise,
- Pump vibrations …

→ Dynamic error budgeting tool ←



Real-time control system is also imperative

CHALLENGES

X-ray Fluorescence Microscopy (2D)

Imaging

3D scan, tomography

X-ray absorption spectroscopy

2D scan, resolution **10nm to 100nm**

2D scan of a **sample** placed in the **X-ray** beam (focal spot size 10 to 100nm)

the elemental composition is determined by fluorescence **detectors**

LASER compression

High T ~5000 K
High P ~400 GPa

SPACE CONSTRAINTS

→ space is needed to build stiff and stable support for the sample ←

As a consequence, the KB will be **suspended upside down** : need a frame that surrounds the sample stages