Nanoprobe Results

Metrology & control in stacked closed-loop systems

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Introduction – Context & overview

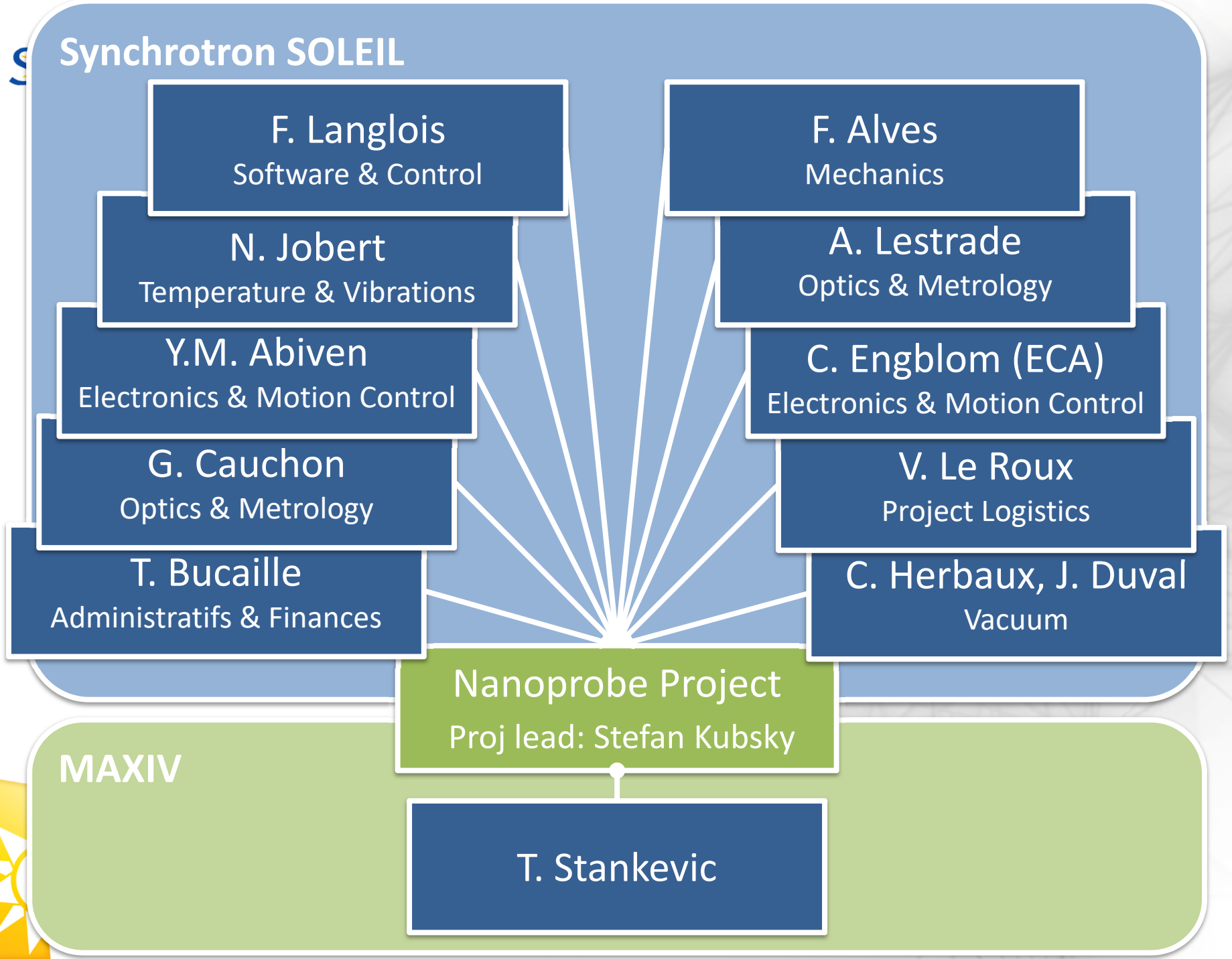
- Nanoprobe Project: 4- year collaboration between Synchrotron SOLEIL & MAX IV (2013-2017)

- Produce Nanoprobe endstation prototype capable of 2D- & 3D tomography on the nanometric scale
  - Beam focusing stages
    - Central Stop (CS)
    - Double Fresnel Zone Plates (FZP)
    - Order Sorting Aperture (OSA)
  - Sample Stage

Introduction – Challenges & approach

- Nanoprobe Endstation Challenges
  - Nanometer resolution + mm- range over XYZ- space
  - Sample 360° rotation over Rz-space
  - Stepscans
  - Flyscans
  - Long-term stability

- Approach
  - Stacked, compact, & modular designs
  - Interferometry for stage characterization
    - Linear drives
    - Rotational drives (method developed in-project)
  - Interferometry implemented in advanced modes of control
    - Delta Tau Powerbrick LV, Attocube FPS 3010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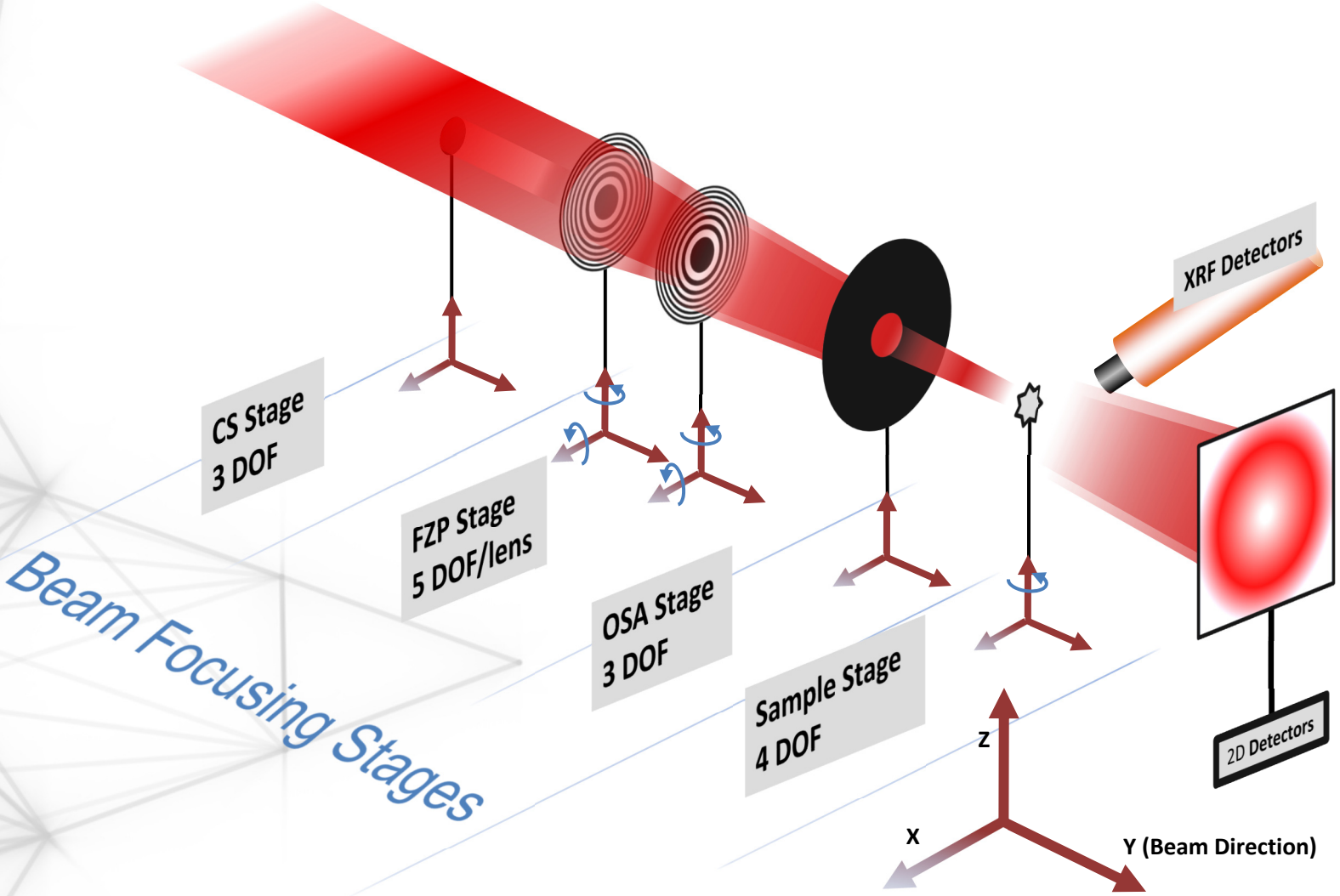
Introduction - Context & overview



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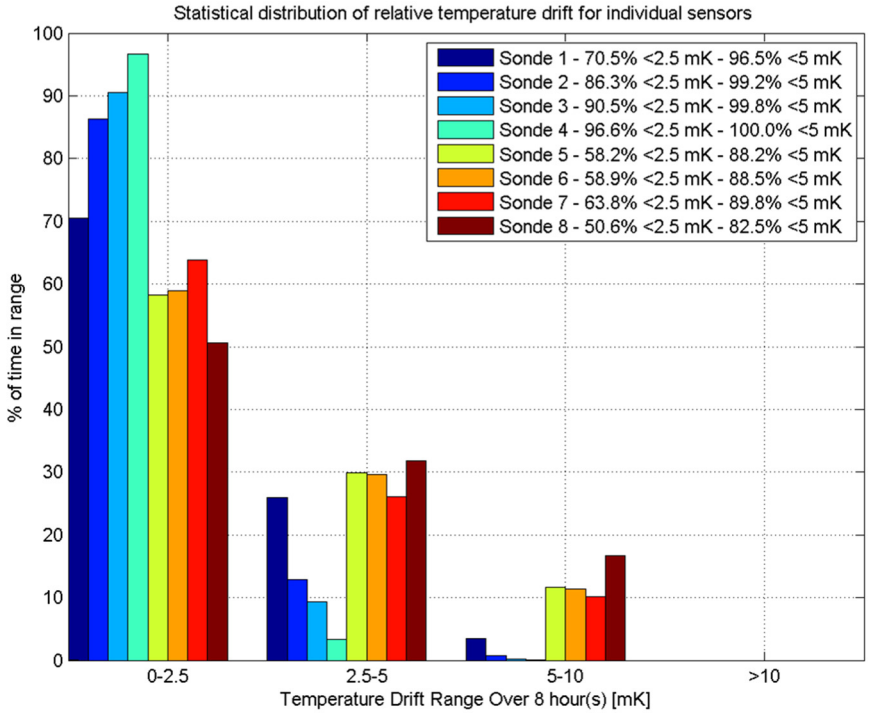
Environment

- Climate controlled room
- Marble table
  - Insulation (minimize XY- gradients)
  - Water circulation (thermal impedance)
- Enclosed space (thermal impedance)

Environment



- Better than 1mK resolution over 1000mK intervals
- Long-term (~8h) temperature drifts ≤ 10mK (~10nm)
- XY- temperature gradients low

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  - Rotation- scan results
- Fresnel Zone Plate Stage
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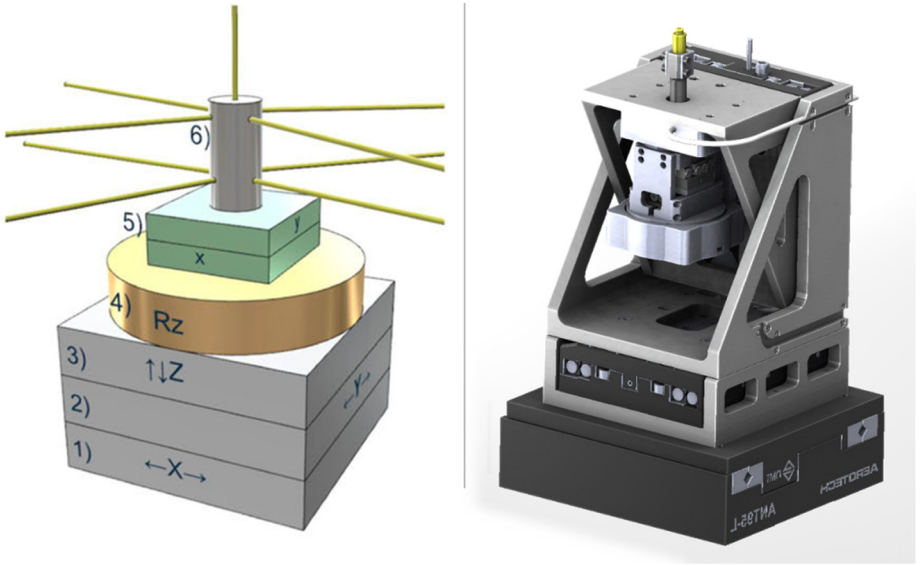
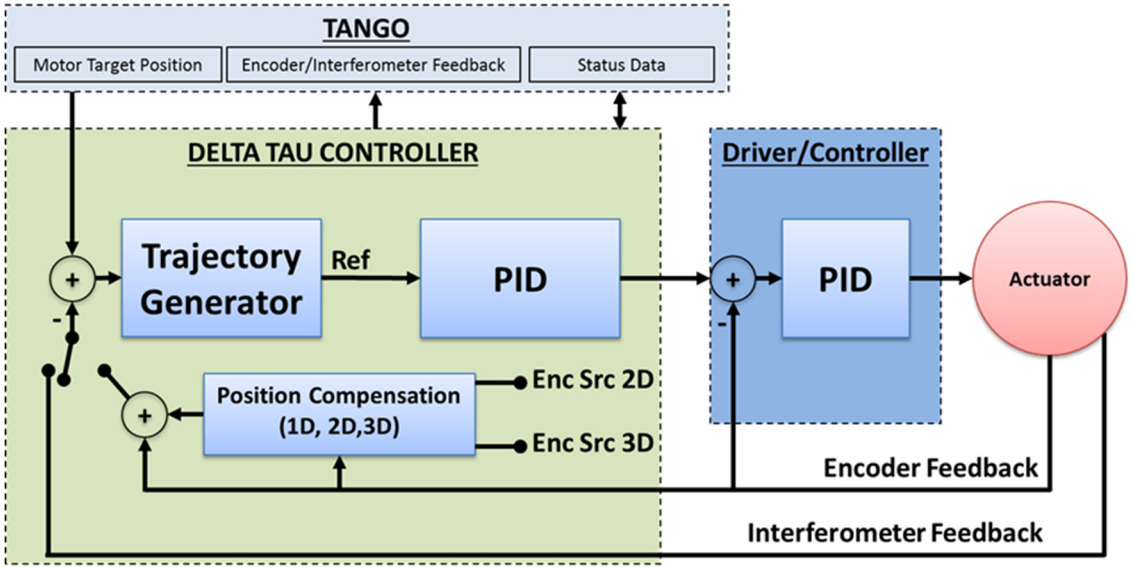
  - Long-term active stabilization results
- FZP-sample stability
- Summary & Conclusion

Sample Stage - Setup



- Stacked design
  - 1 (X): flyscan
  - 2-4 (Y, Z, Rz): stepscans
  - 5 (x,y): sample alignment
  - 6: Sample holder + interferometry reflector (sample tracking)

Sample Stage - Setup

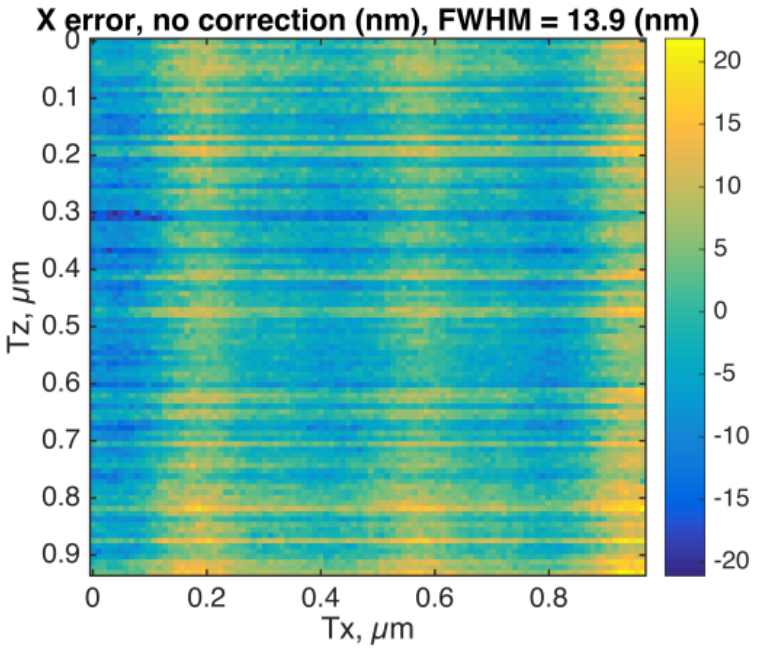


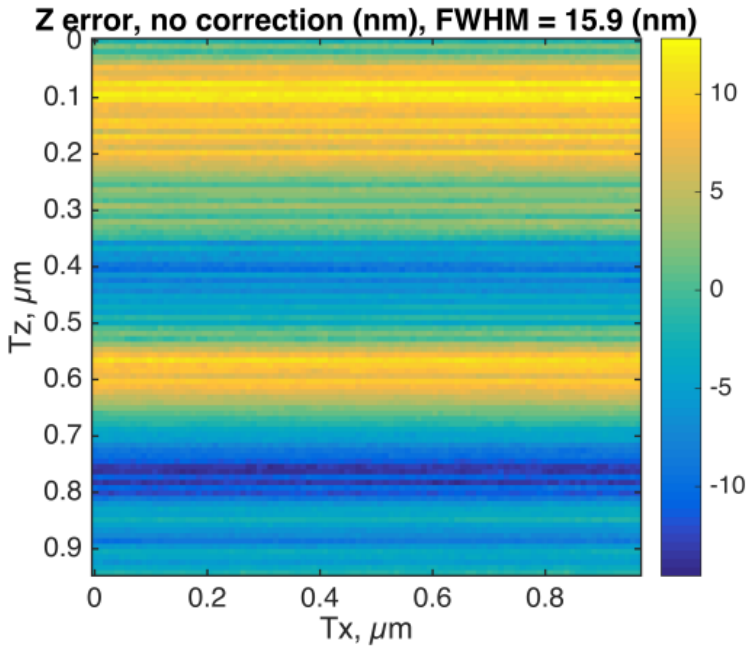
- Control →Cascaded
  - Inner loop (high-frequency, 400-4000Hz): Driver/Controller
  - Outer loop (lower frequency, → 2000 Hz): Delta Tau
  - Delta Tau ⇔ TANGO interfacing via ethernet
- Compensation Tables (feedforward)
- Interferometry feedback control

Sample Stage: 2D- Scan Results

- Trajectory errors during 1x1 µm XZ-scan

Encoder feedback, no feedforward, no interferometer feedback

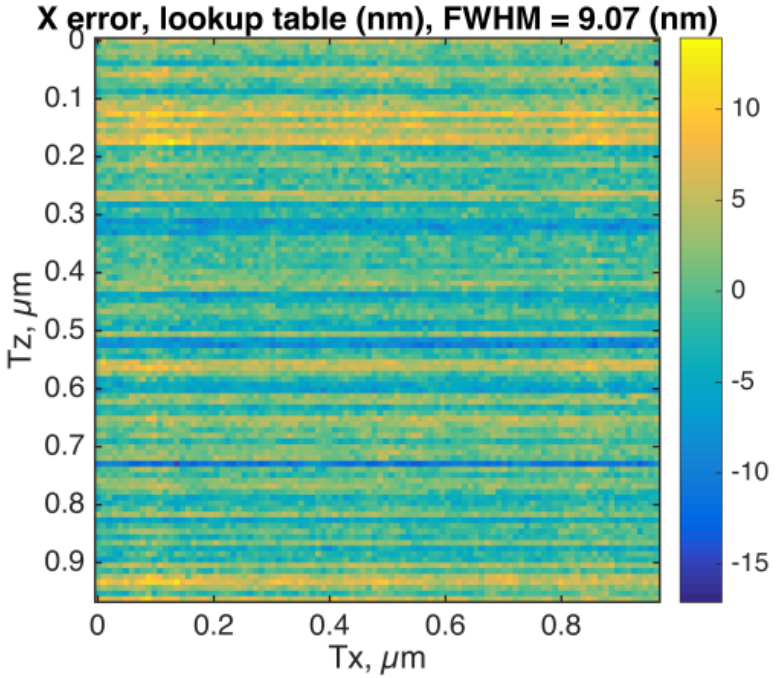


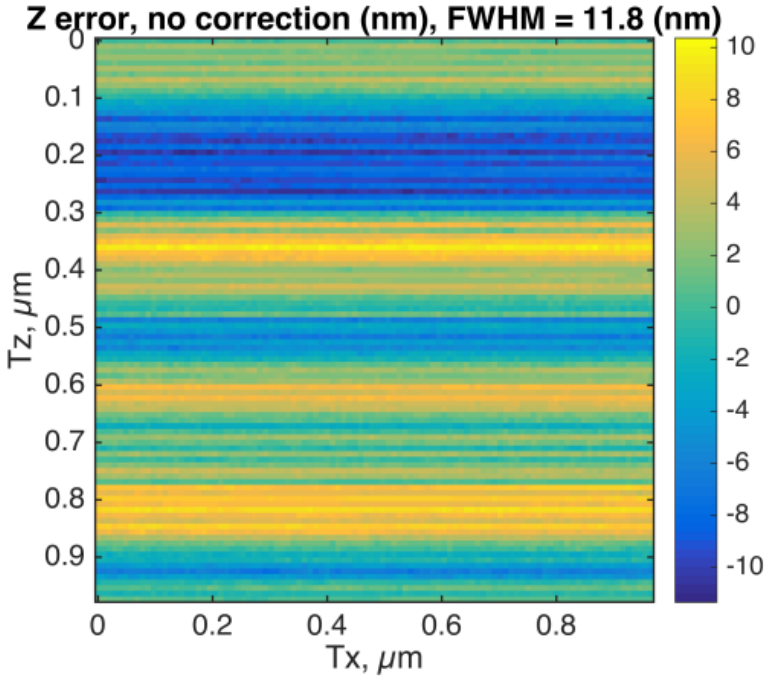


Sample Stage: 2D- Scan Results

- Trajectory errors during 1x1 µm XZ-scan

Encoder feedback, **X- feedforward**, no interferometer feedback

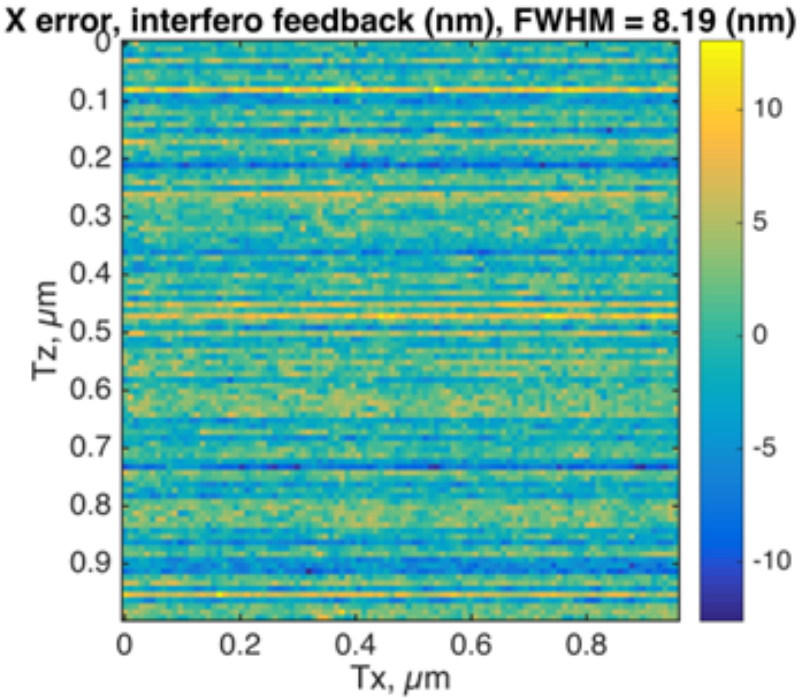


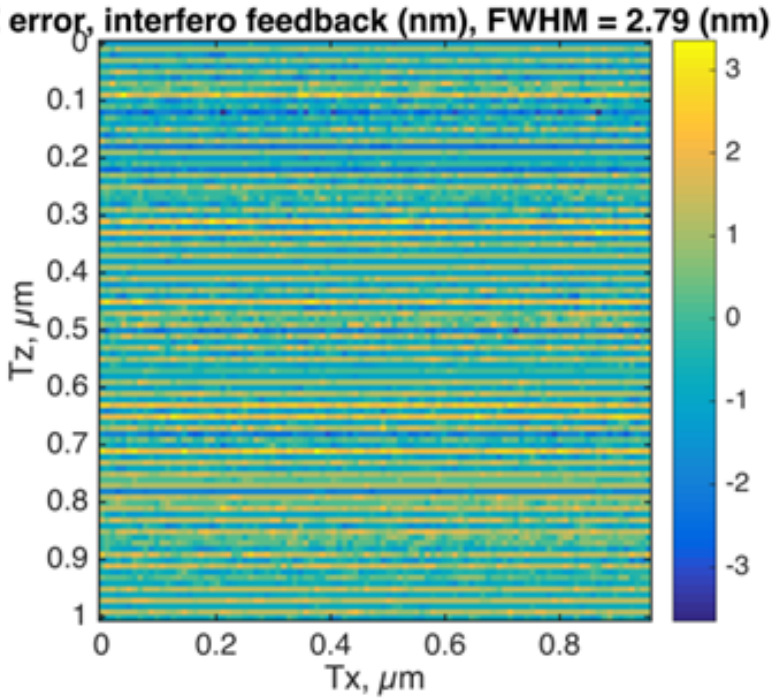


Sample Stage: 2D- Scan Results

- Trajectory errors during 1x1 µm XZ-scan

Encoder feedback, no feedforward, **XZ- interferometer feedback**

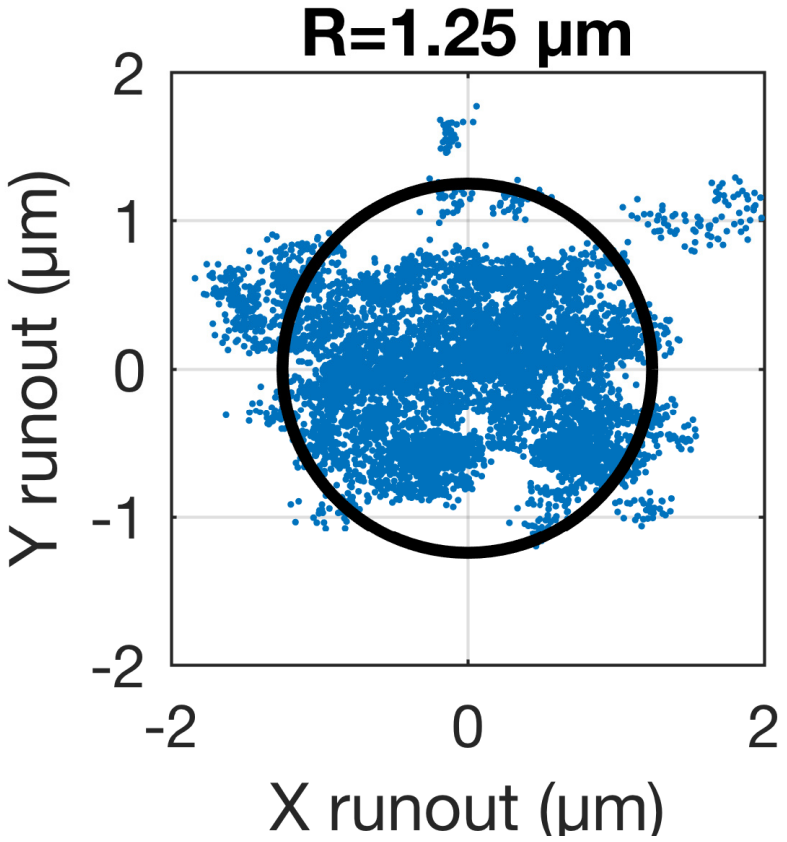




Sample Stage: Rotation scan results

- Trajectory errors during 360° sample rotation scan

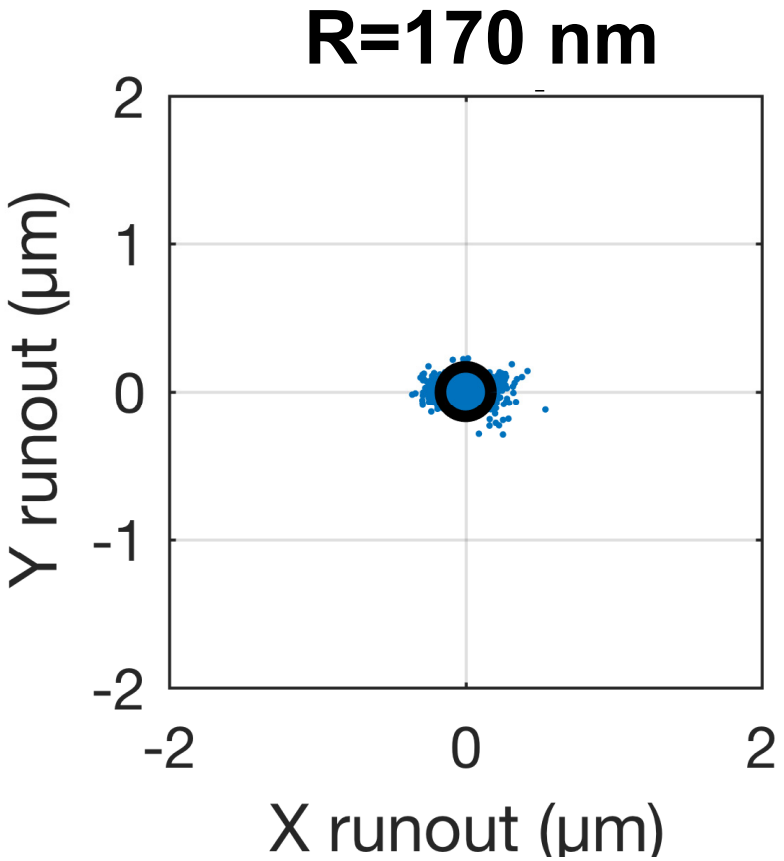
Encoder feedback, no feedforward, no interferometer feedback



Sample Stage: Rotation scan results

- Trajectory errors during 360° sample rotation scan

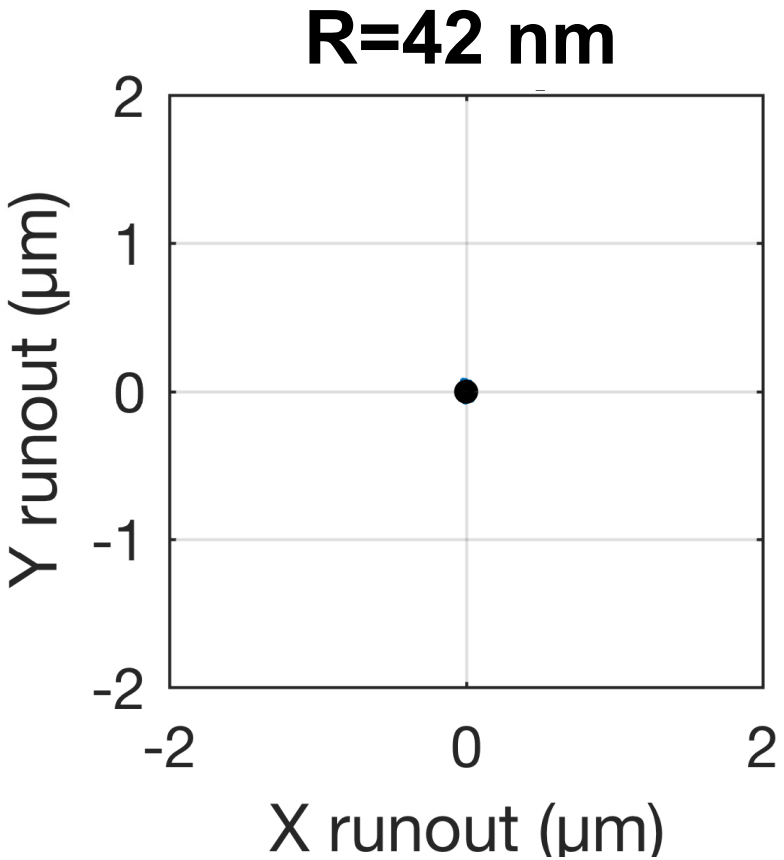
Encoder feedback, **XY-feedforward**, no interferometer feedback



Sample Stage: Rotation scan results

- Trajectory errors during 360° sample rotation scan

Encoder feedback, **XY-feedforward**, **XY-interferometer feedback**



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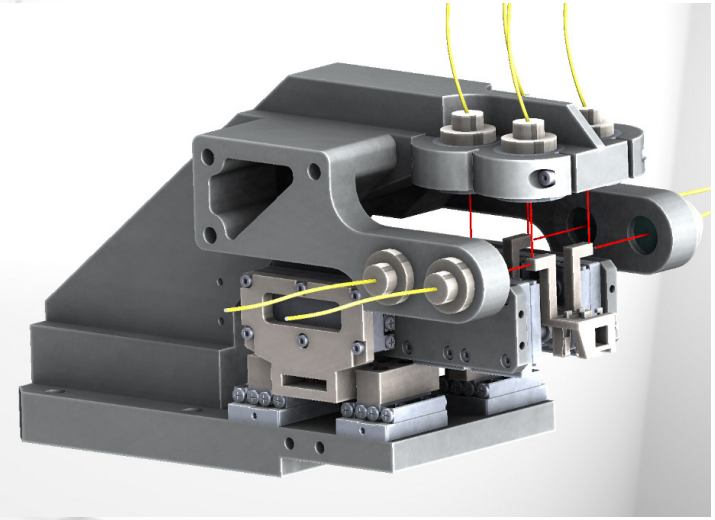
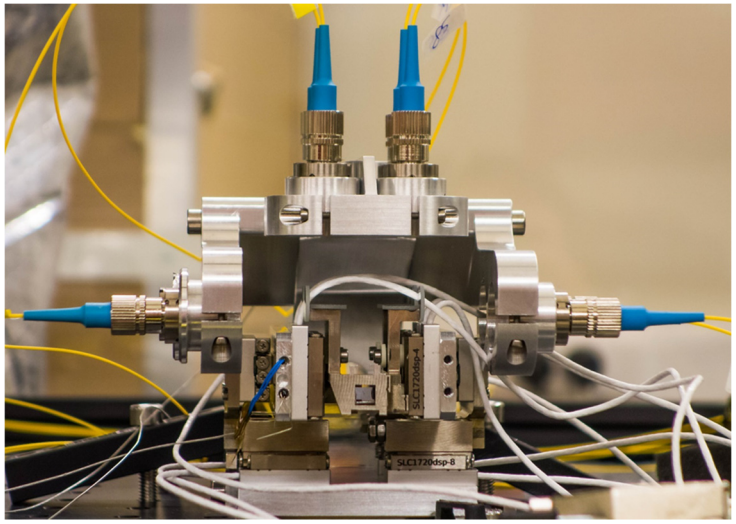
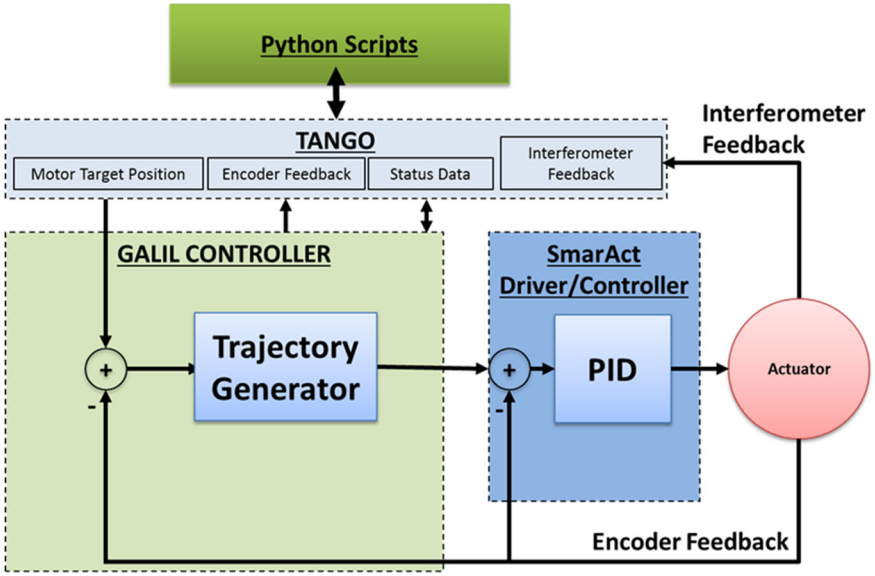
Sample Stage - Setup





- Stacked + parallel structures with interferometry feedback
  - 2 mirror-imaged identical modules, each holding a FZP
  - Static stability

FZP Stage - Setup

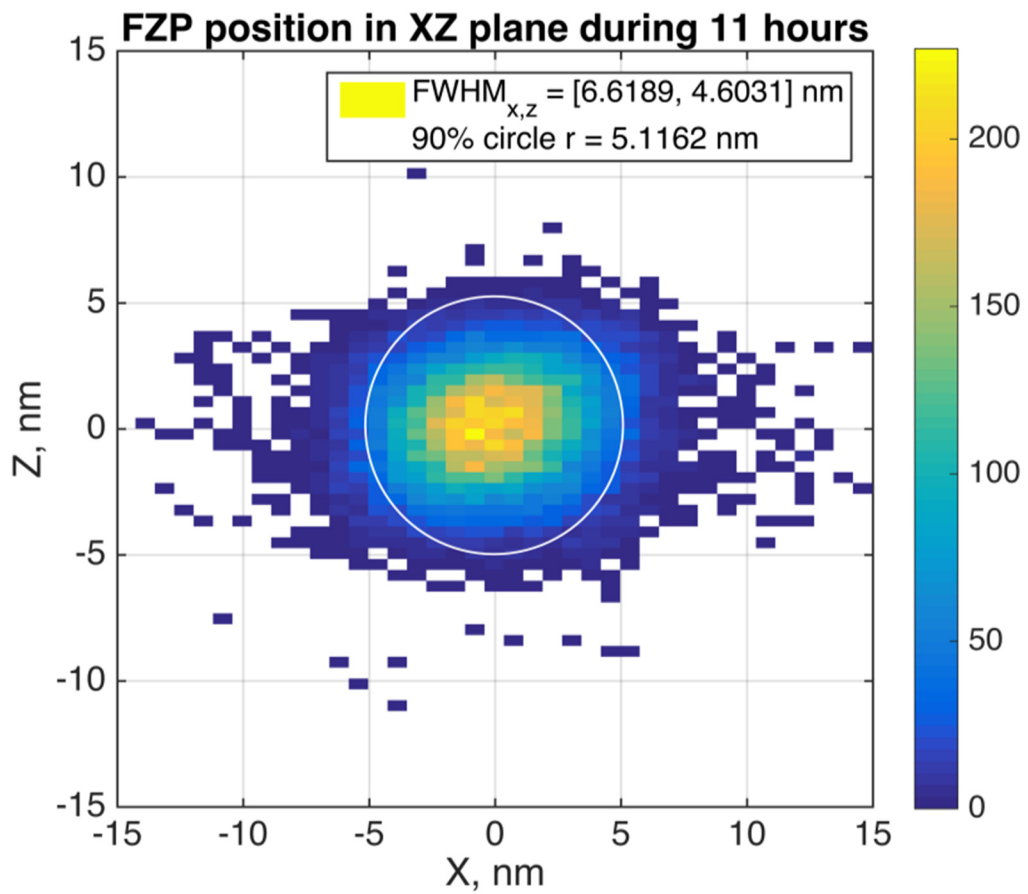


- Control →Cascaded
  - Inner loop (high-frequency, 18kHz): Driver/Controller
  - Outer loop (lower frequency ≤ 1 Hz): Galil/TANGO
  - Python scripts executing TANGO commands
- Interferometry feedback control
- Multi-axis control with kinematic conversions (Python)

FZP Stage: active stabilization results

- XZ- position stability during 11 hours

Encoder feedback, no feedforward, **(X,Z,Rx,Rz) interferometer feedback**



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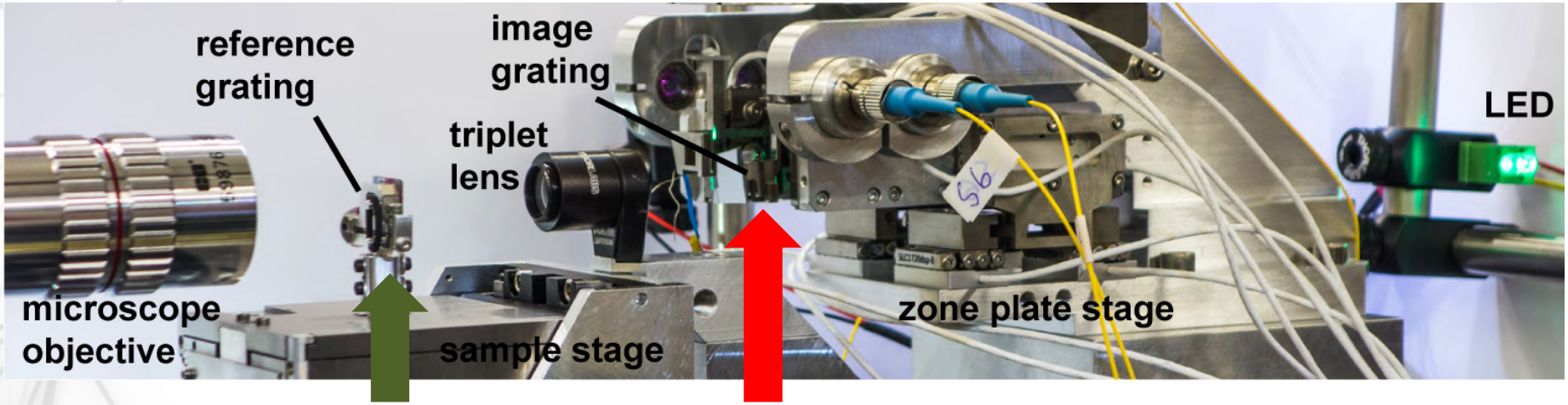
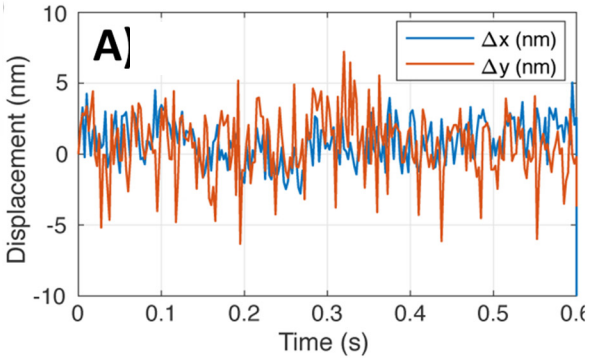
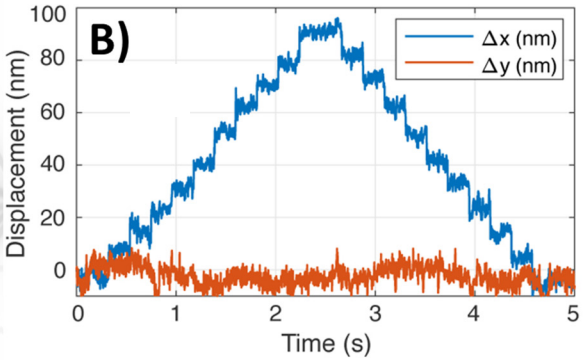
FZP-sample stability

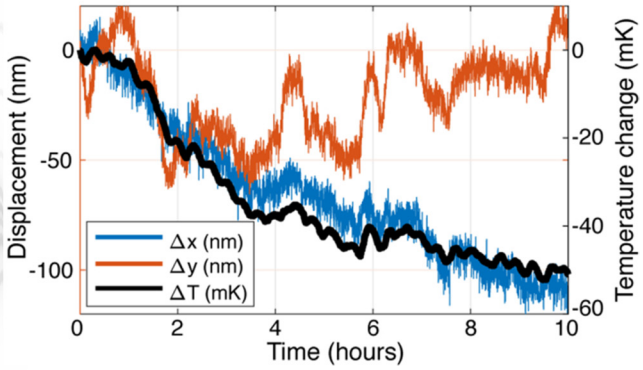


- XY- stability between Sample (green) and FZP (red)
  - Evaluated with Moiré metrology method using 2 overlapping repetitive structures

FZP-sample stability







Steady-state stability over 0.6s

- Encoder closed-loop control
- **Results: +/- 5nm pp steady-state**

Sample stage, pyramid stepscan

- 10 nm sample stage X- steps
- **Results: Decoupling on Y**

Long term thermal drifts (10h)

- **Results: ~60 mK temp drifts**
- **Results: ~100nm X- drifts**

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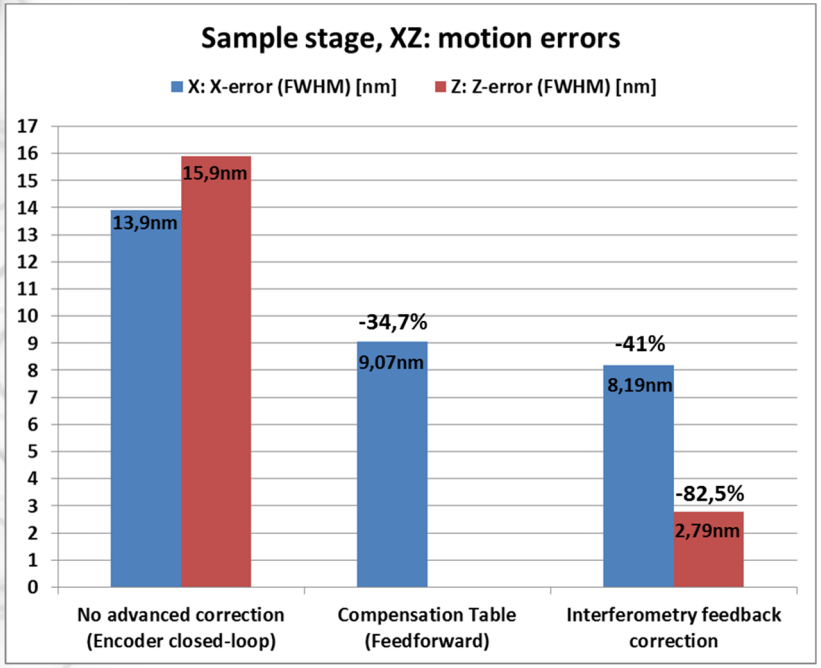
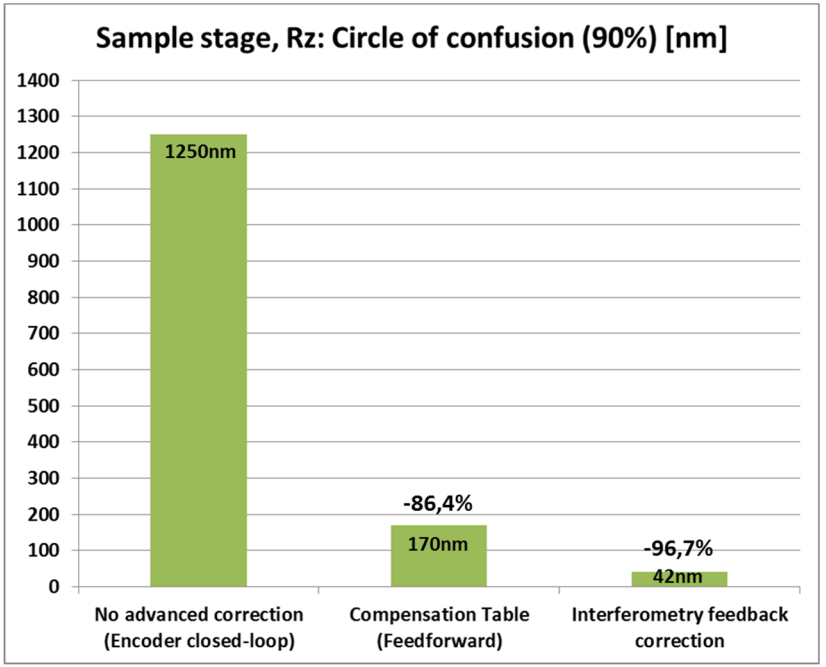
Summary

- ✓ Environment stability: 10mK drifts over 8h
- ✓ Sample stage performance characterized using advanced modes of control





Summary

- ✓ FZP long-term stability: 5,11nm FWHM over 11h
- ✓ FZP-sample stability verified
  - ✓ +/- 5nm pp over 0,6s
  - ✓ XY decoupling
  - ✓ ~100 nm over 10 hours

Conclusion

- Concept proves successful: small, modular stages with;
  - Nanometric stability: Sample stage & FZP stage (and between)
  - Sample stage XYZ- scans with motion errors less than 10 nm
  - Sample Stage Rz- scans with motion errors at 42 nm
- Important to use:
  - Stage characterization with interferometry → → Feedforward Compensation Tables
  - Interferometry feedback control

- **Interferometry feedback working area**
  - **Can be increased by altering sample reflector**
- **Feedforward compensation table working area**
- **Data acquisition system → PandABox**
  - **TUAPL05, S. Zhang (PandABox System)**

Some references

"Interferometric characterization of rotation stages for X-ray nanotomography"
Review of Scientific Instruments, May 2017

"Method and device for the three-dimensional characterisation of a surface of an object"
Patent App WO2016078841 A1

"Moiré method for nanometer instability investigation of scanning hard x-ray microscopes"
Optics Express, May 2017