Positioning system of a metrological AFM: design considerations

AFM workshop
LNE, Trappes

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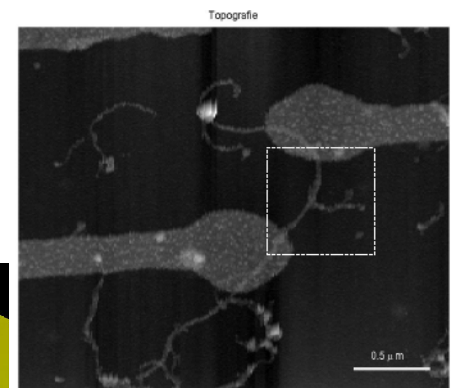
Overview

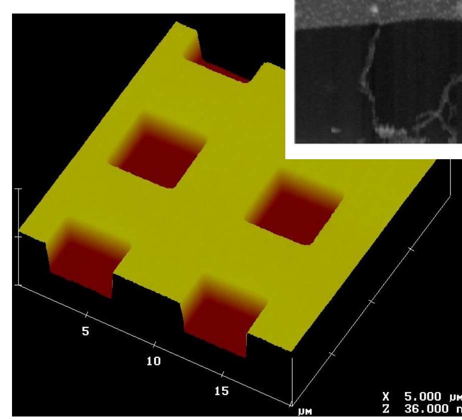
- Introduction
- General layout metrological AFM
- Layout of the positioning system
- Fine positioning unit
- Sample holder
- Coarse approach mechanism
- Conclusions

Introduction

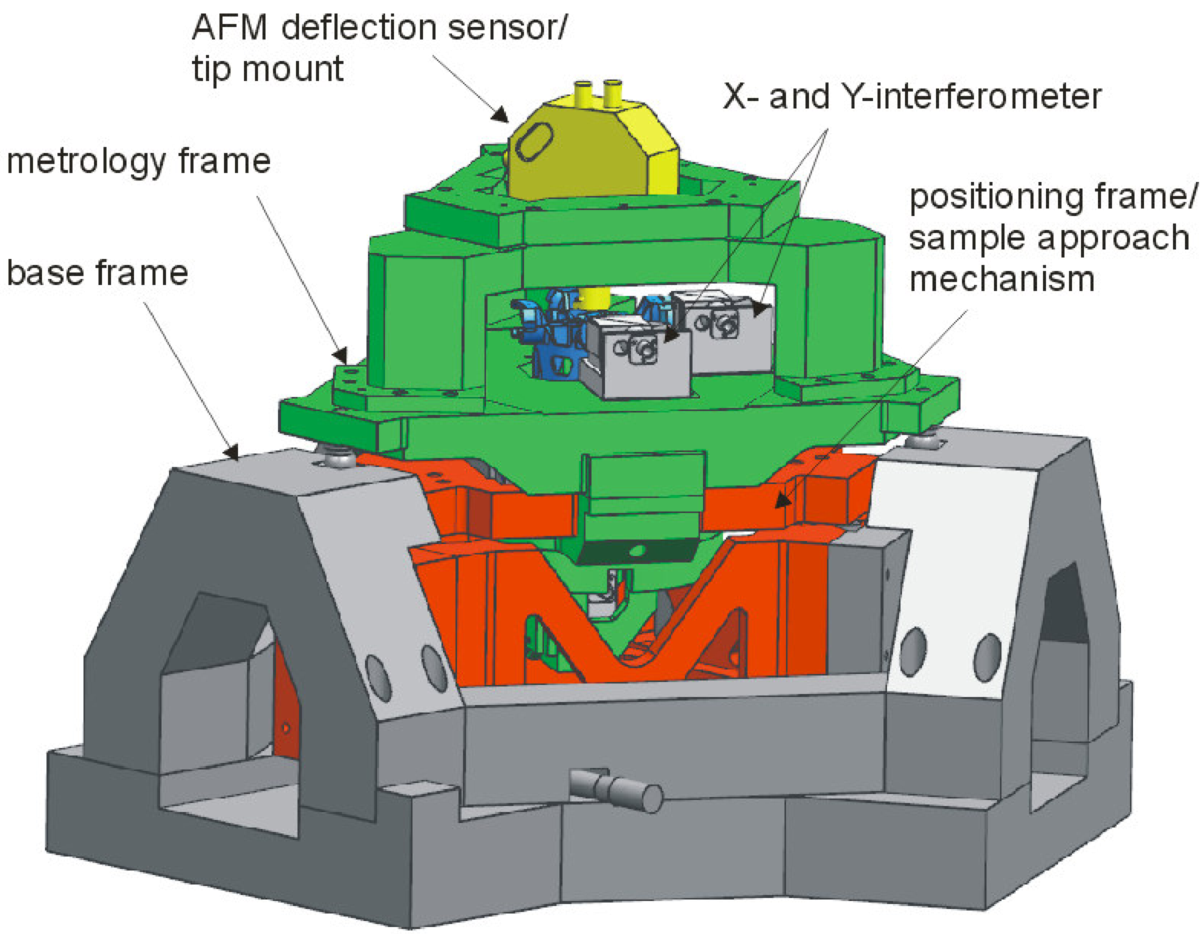
Project goal

- Calibration device for traceable measurements
- Designed for FPS Economy, SMEs, Self-employed and Energy
- Specifications:
  - ✓ 1 nm accuracy
  - ✓ stroke of 100 μm x 100 μm x 100 μm
  - ✓ calibration nanogrids
  - ✓ direct measurements

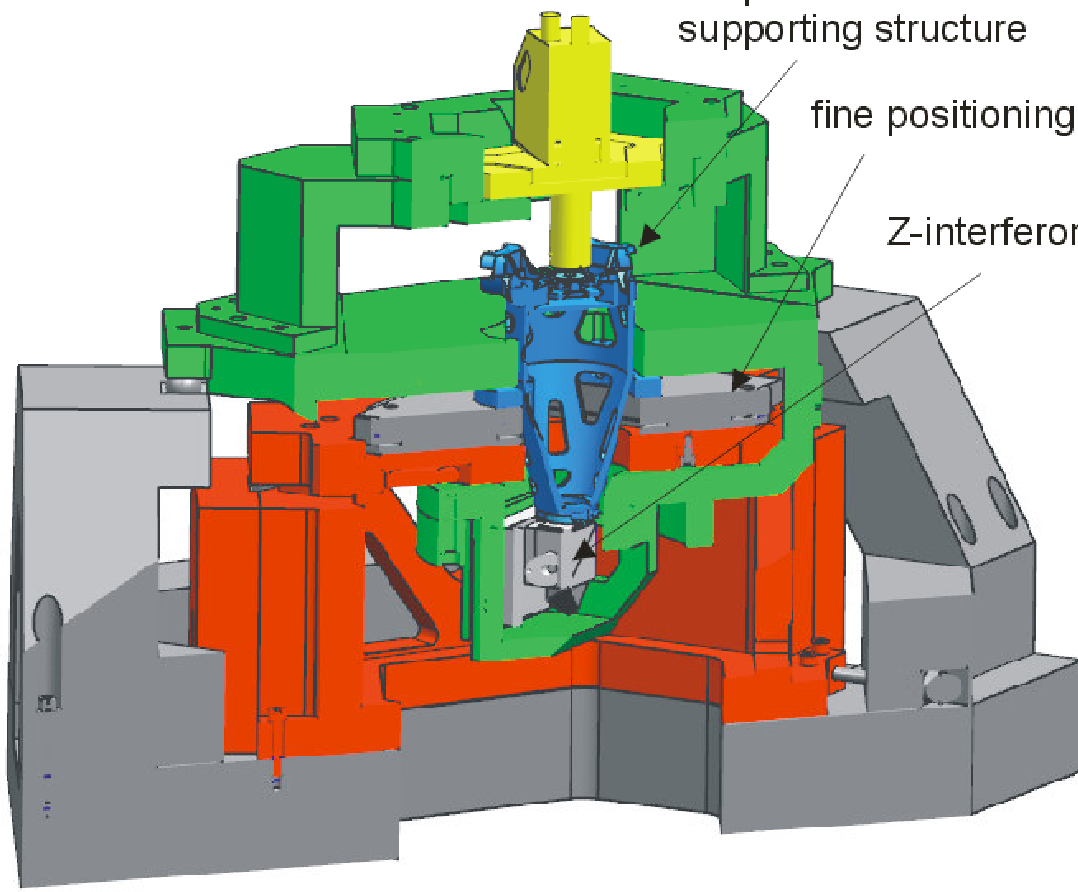




General design considerations



General design considerations



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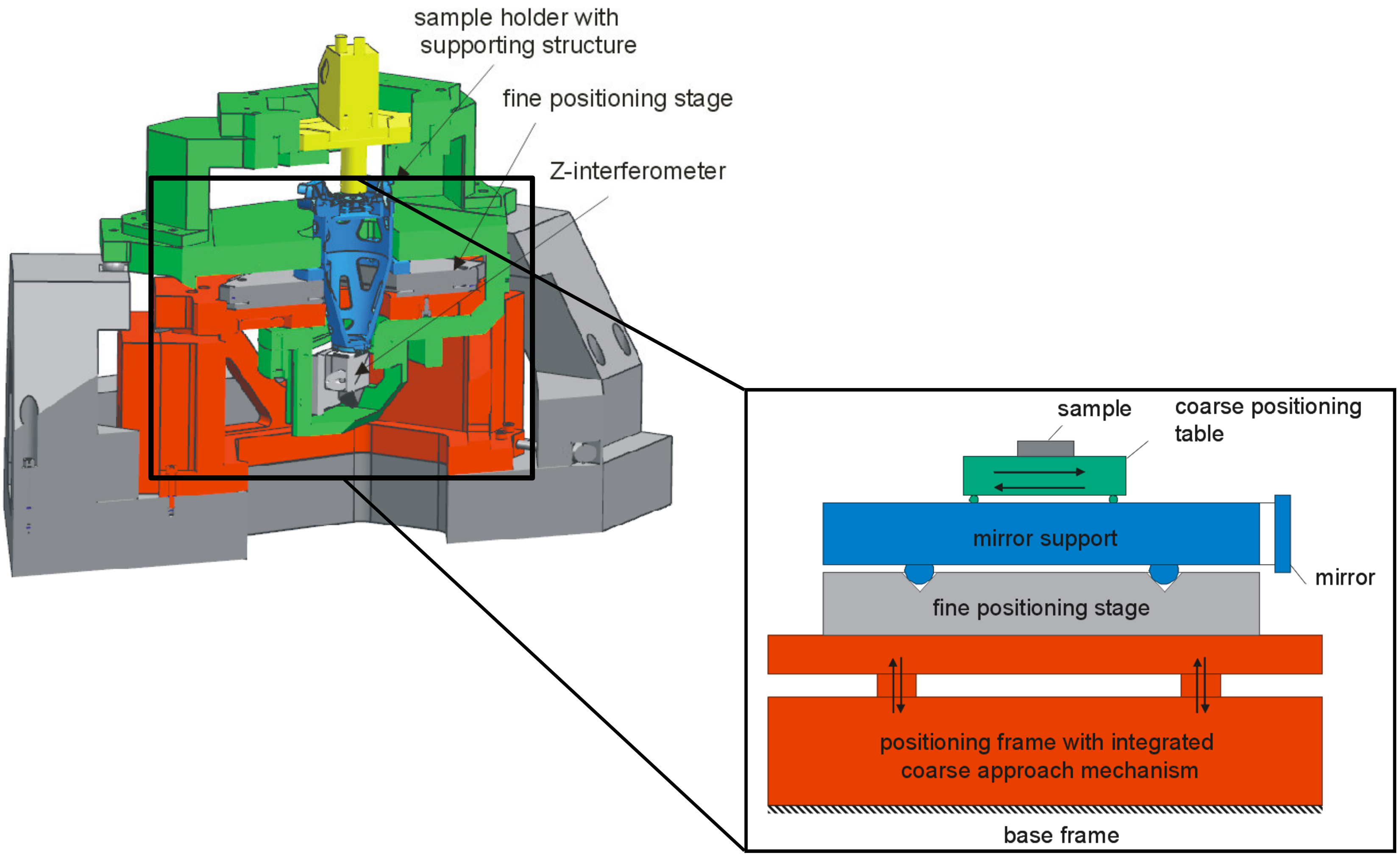
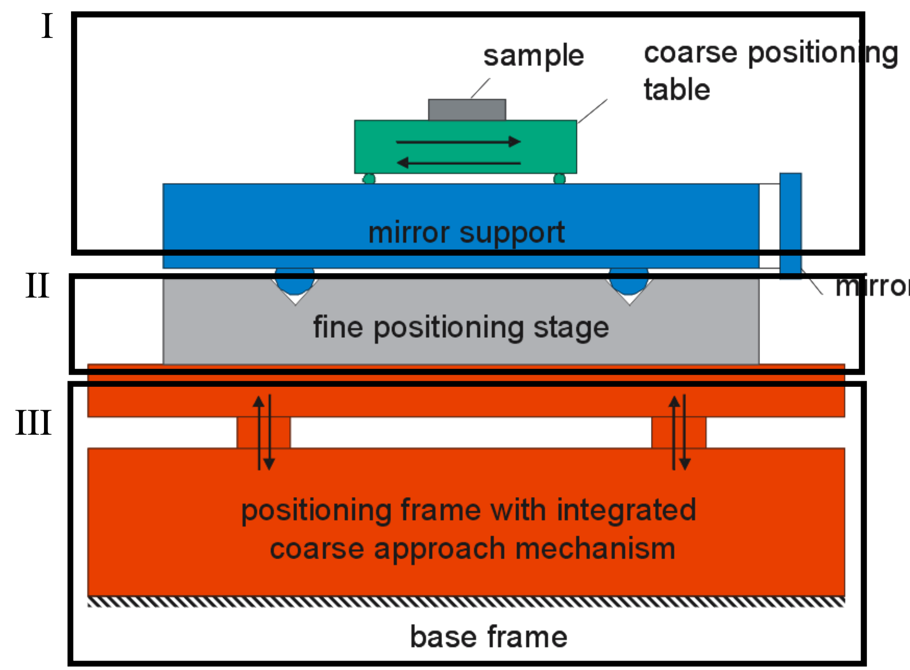
Layout of the positioning system



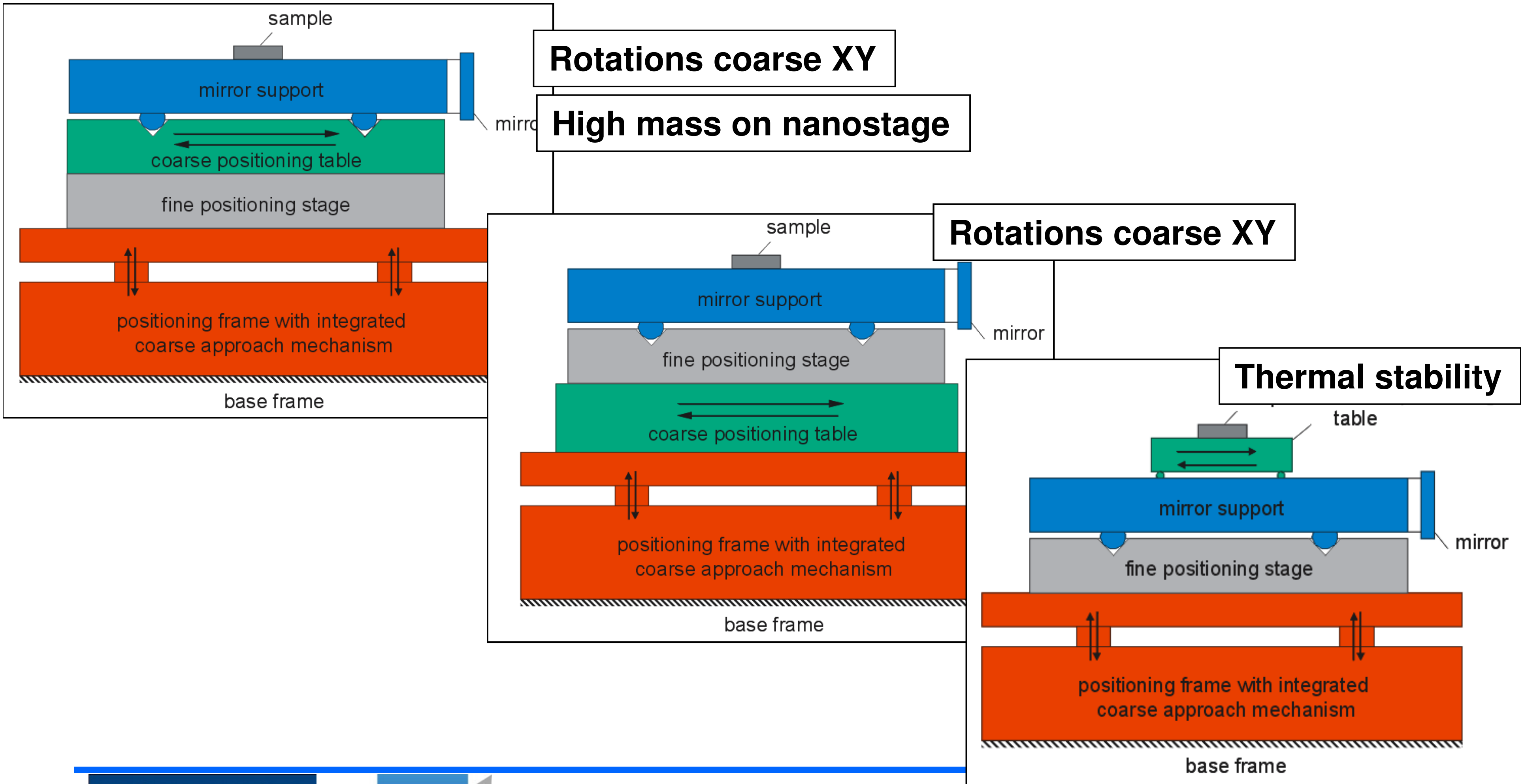
Layout of the positioning system

- Invar sample holder
- No strict requirements on coarse positioning table (between mirrors)
- Compact low mass coarse XY-table
- Abbe point maintained
- Alignment maintained
- Compensation of alignment errors after approach



Layout of the positioning system

Ordering components



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Fine positioning unit: nanostage

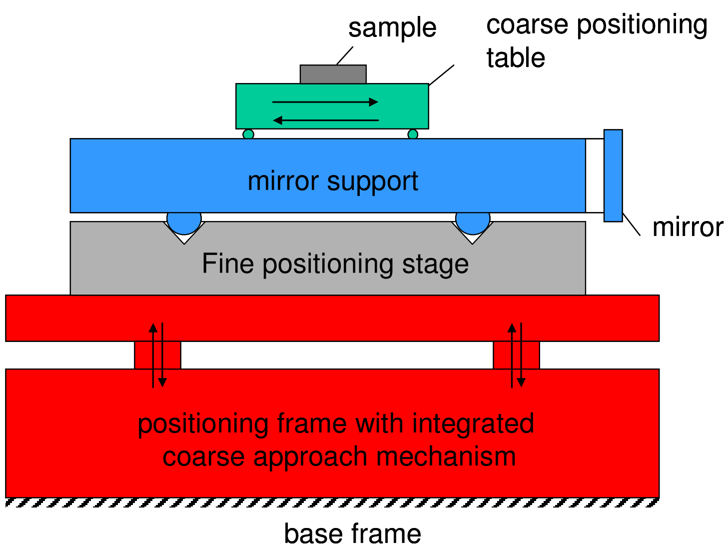
Compromises

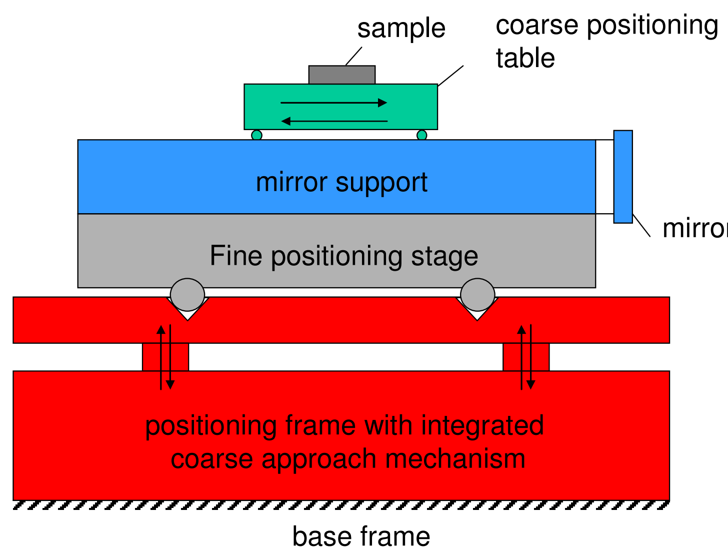
- Serial versus parallel?
  - Bandwidth
  - Parasitic rotation
- Material?
  - CTE
  - Thermal conductivity
  - Costs
  - Mass
  - Kinematic design

Error source	Uncertainty [nm]	
	X, Y	Z
Machine frame		
Abbe error	0.30	0.10
Cosine error	0.05	0.05
Mirror tilt error	0.26	0.15
Mirror orthogonality	0.24	0.24
Thermal drift	1.00	1.00
Interferometers		
Refractive index change	0.48	0.48
Laser wavelength accuracy	0.01	0.01
Laser wavelength stability	0.06	0.06
Mirror flatness	0.63	0.63
Polarisation error	0.40	0.40
Thermal drift	1.00	1.00
Optical system resolution	0.15	0.15
AFM-probe		
AFM resolution	0.60	0.05
Positioning stage		
Stage resolution	0.20	0.20
Result	1.85	1.72

Fine positioning unit: nanostage

Material choice and kinematic mount





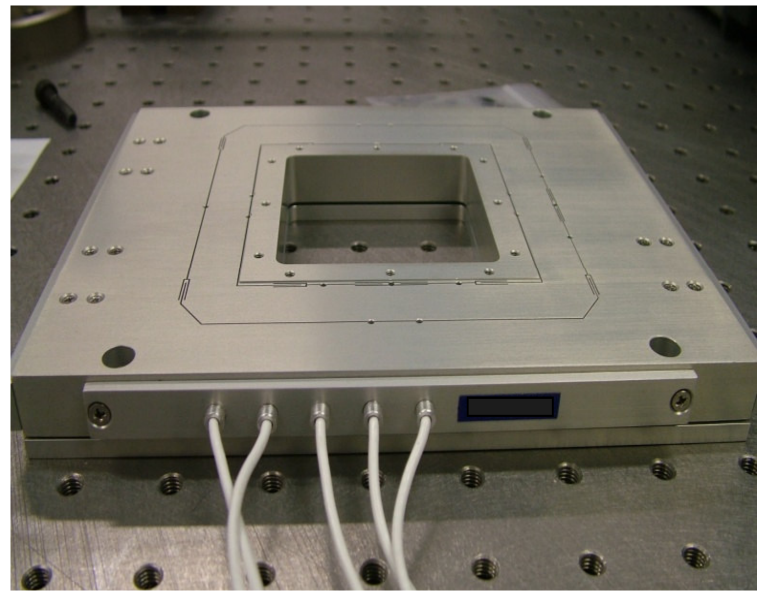
More mass on kinematic mount

Lower resonance frequency

Fine positioning unit: nanostage

Specifications

- Parasitic rotations: 3 µrad
- Resolution: 0.2 nm
- Aluminium
- Low profile
- Stiffness: 1 N/µm



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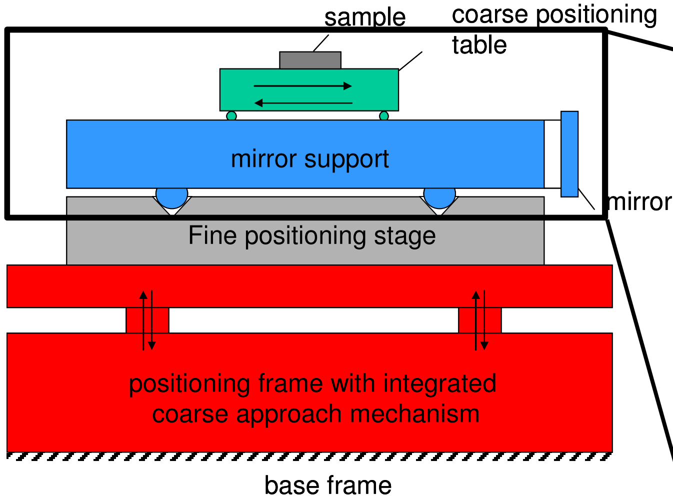
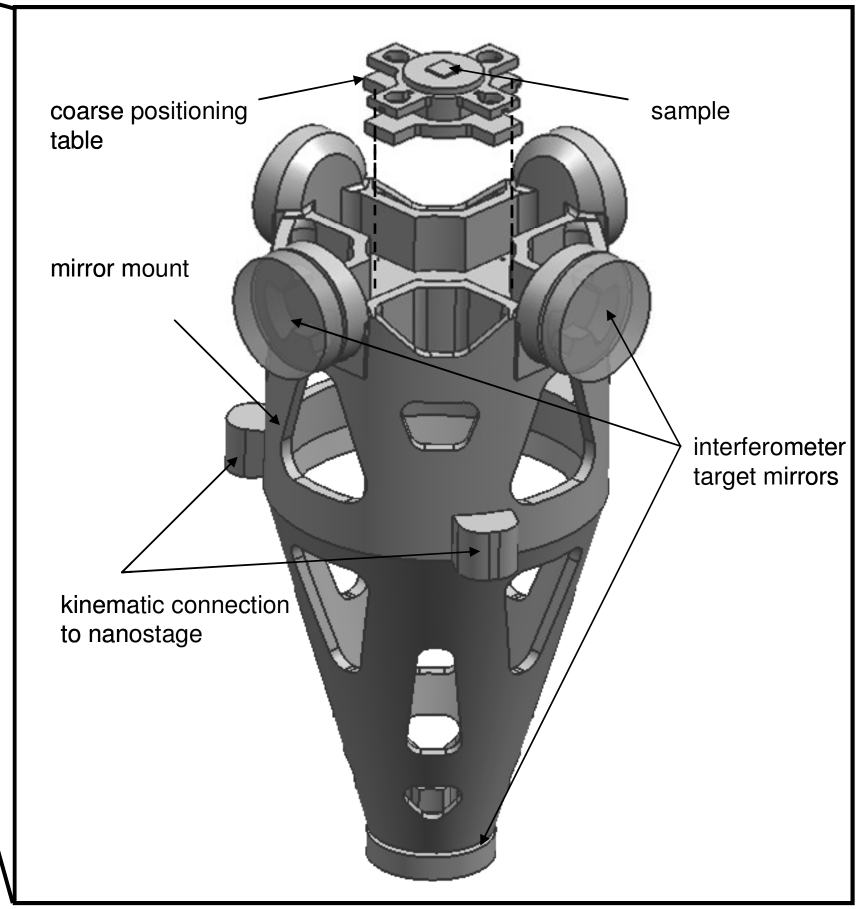
Sample holder design

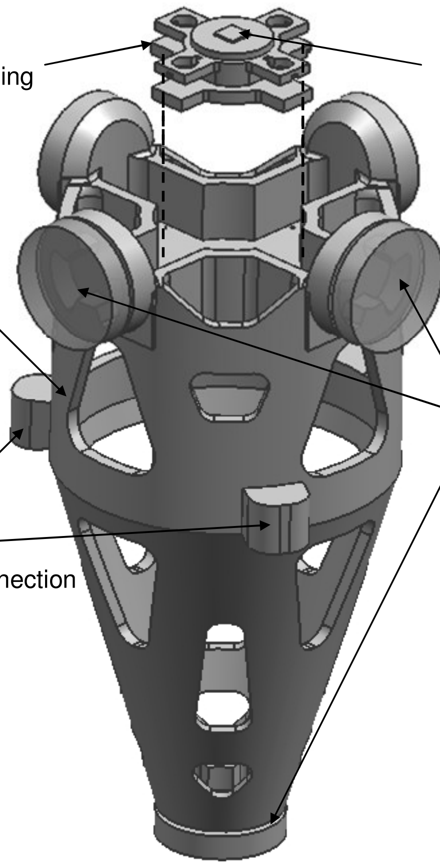




Sample holder design

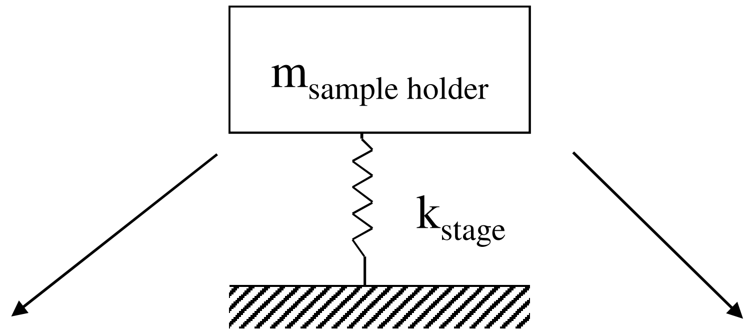
Properties

- Invar (part metrology loop)
- Coarse XY no influence on alignment
- Mass : 0.65 kg
- Compromise: stage resonance versus component stiffness



Sample holder design

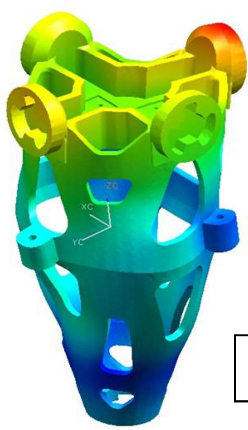
Compromise: nanostage resonance versus component stiffness



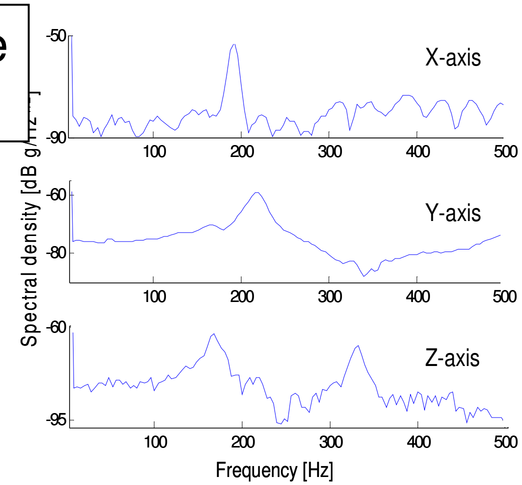
High mass for design tolerances

Low mass for high resonance

Place mass where it needs to be using simulations

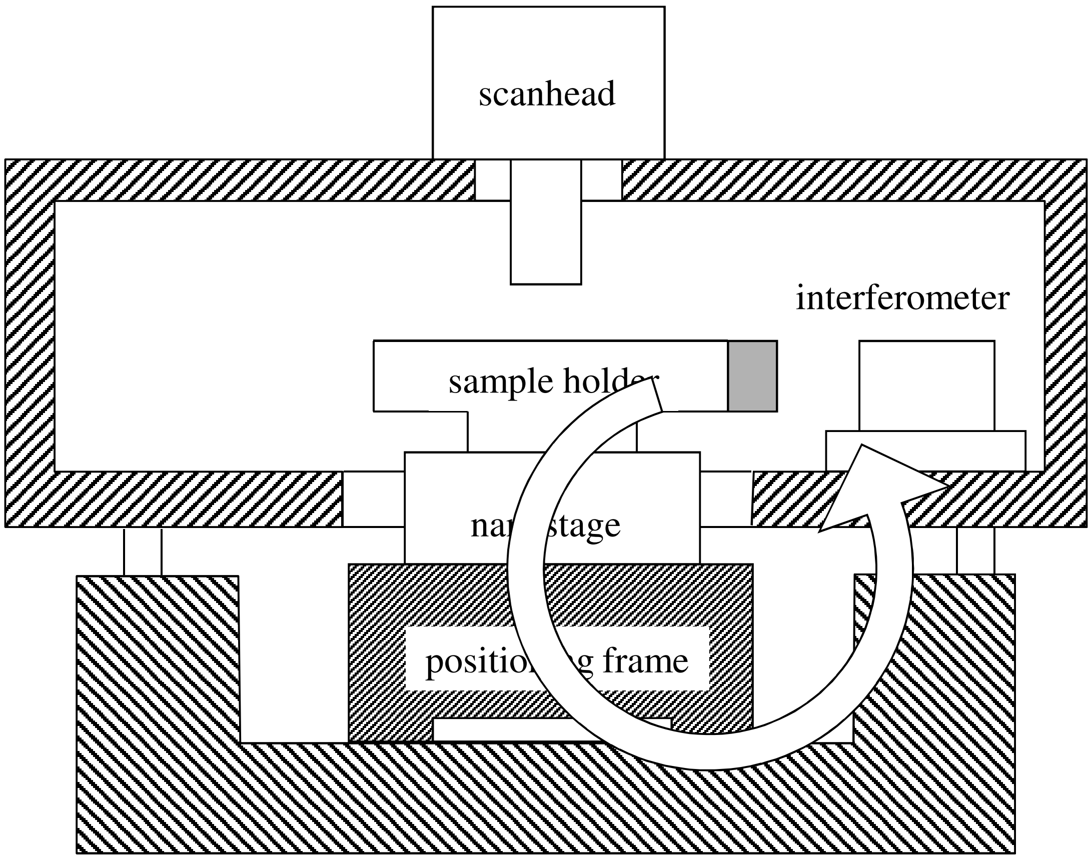


1750 Hz



Sample holder design

Thermal design



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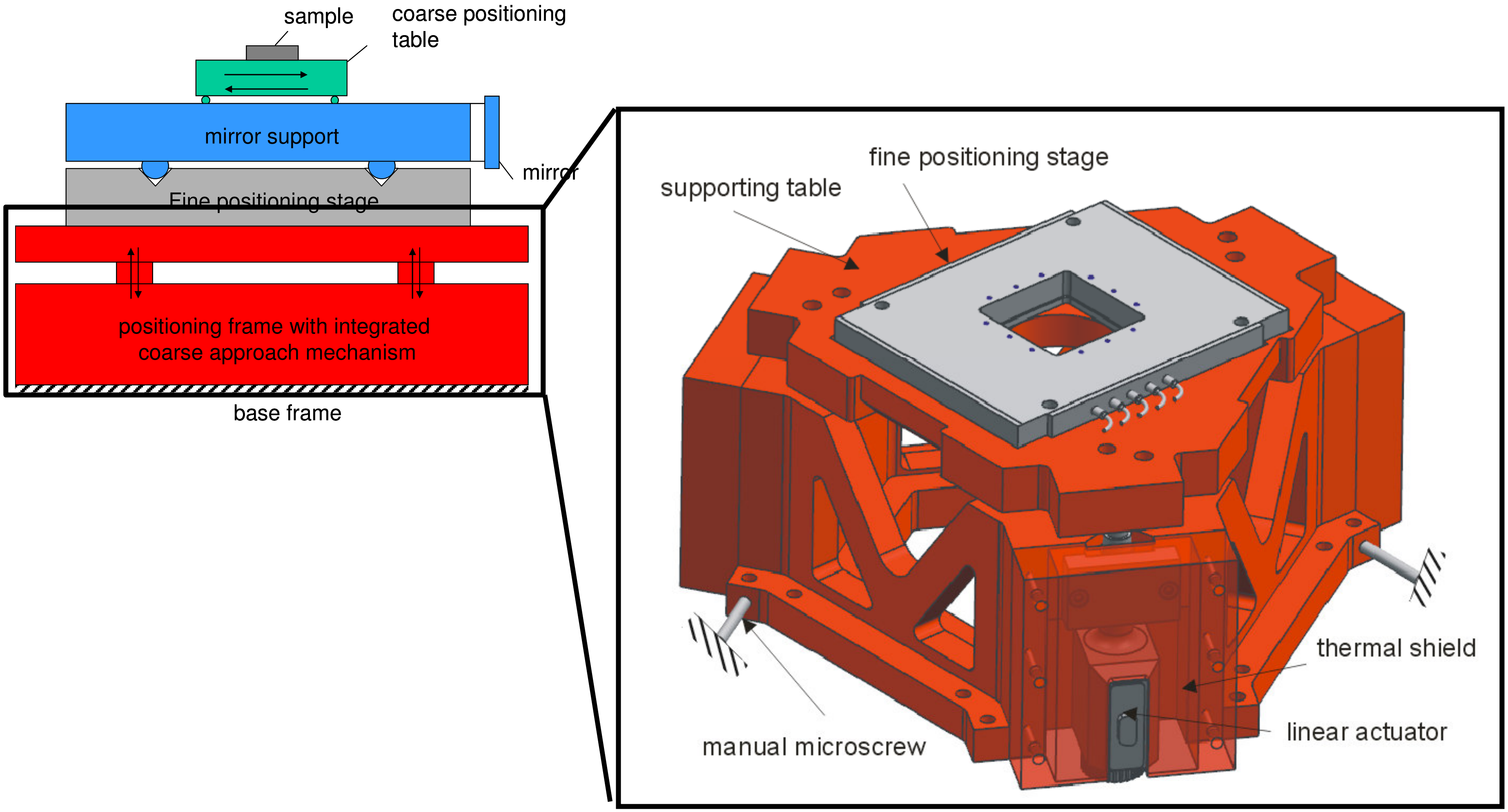
Sample approach mechanism

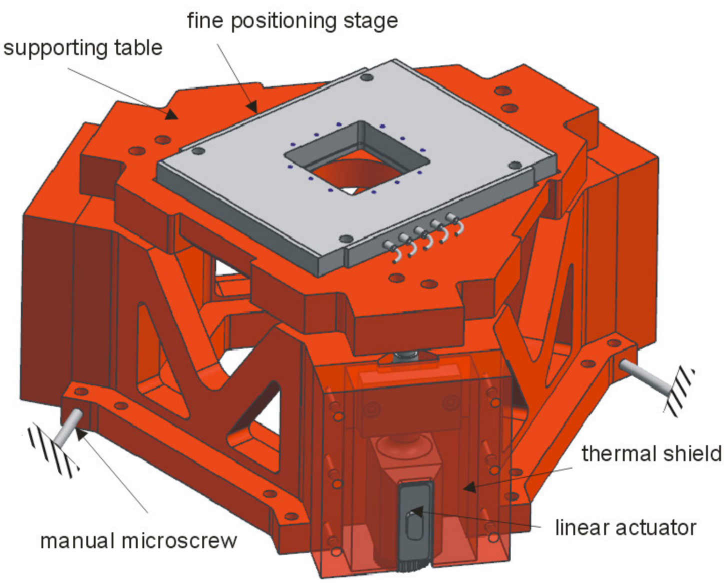
- Functions
  - Approach sample to probe tip
  - Align sample to frame
- Requirements
  - Mechanical stability
  - Thermal stability
  - Safe approach
  - Sufficient alignment possibilities

Sample approach mechanism

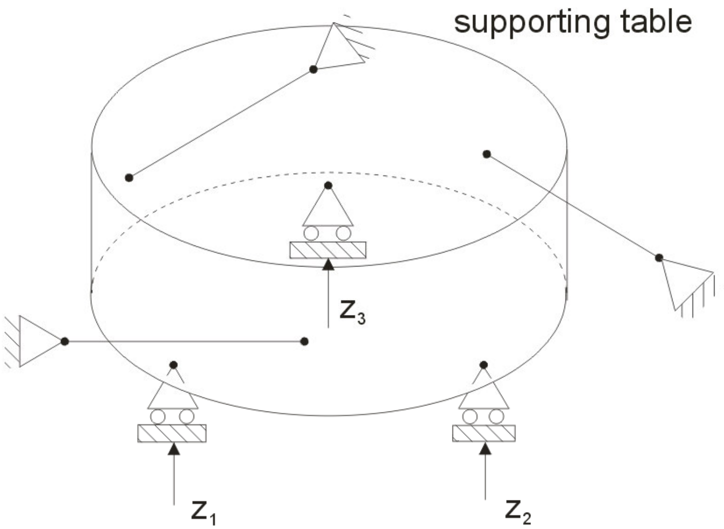


Sample approach mechanism

Specifications	
Mechanical	• automated approach • 1.3 μm resolution • 1 mm stroke
Thermal	• no heat production during scan • fast thermal settling time
Alignment	• alignment accuracy of 45 arcseconds in X- and Y-directions • alignment accuracy of 25 arcseconds in X- and Y-directions • rotation range of 0.4 degrees
Robustness	• safe approach
Material	• aluminium (rigid connection to base)

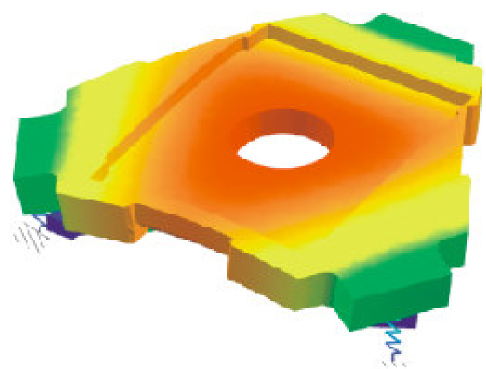


Sample approach mechanism



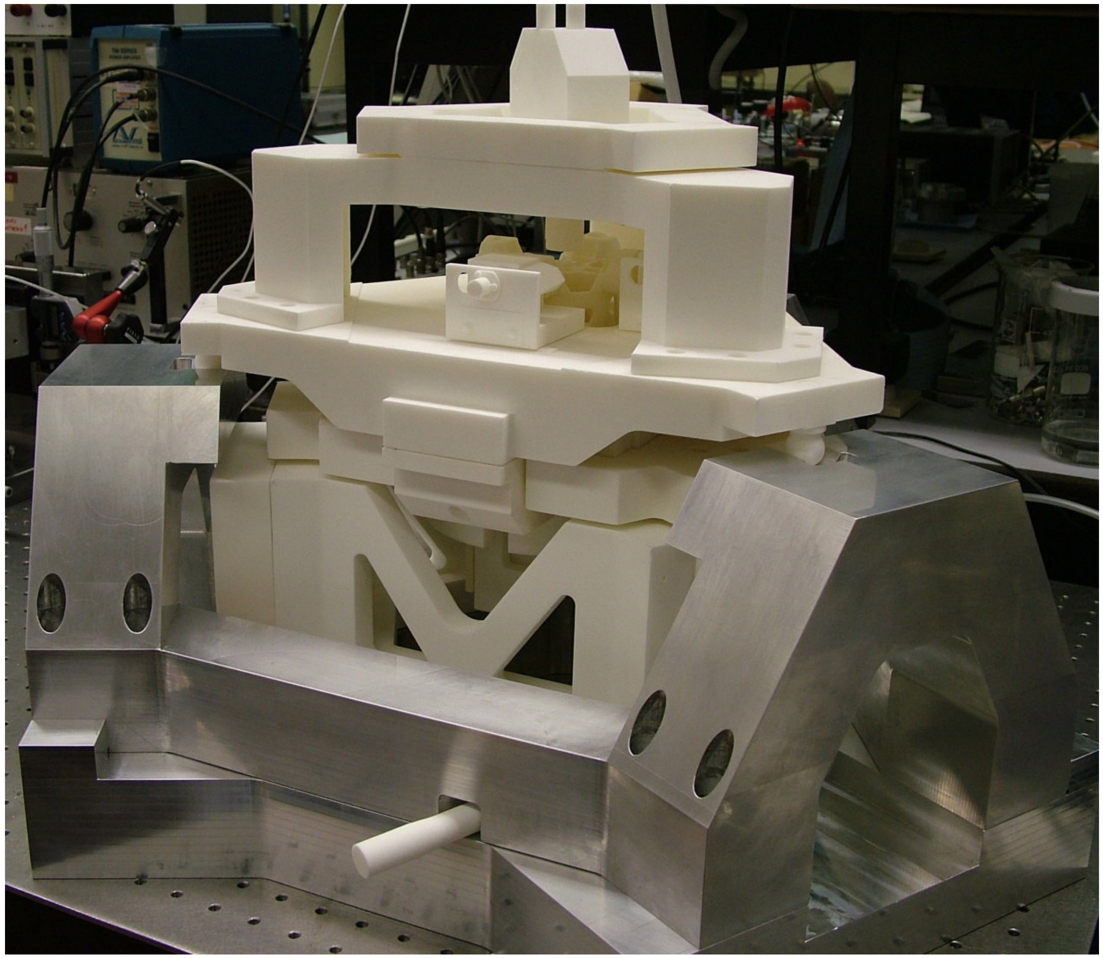
Considerations

- Kinematic design (stiffness!)
- Alignment possibilities (stiffness!)
- Careful design of rods



$F_{res} = 440$ Hz

Prototype



Conclusions

- Positioning system: ordering components
- Fine positioning unit
  - Parasitic rotations
  - Material choice
- Sample holder
  - Component stiffness
  - Nanostage resonance frequency
- Sample approach mechanism
  - Resonance frequency
  - Kinematic mounting, stroke