PAUL SCHERRER INSTITUT

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Mechanics for Positioning: Flexure-Based Positioning Systems

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Contents

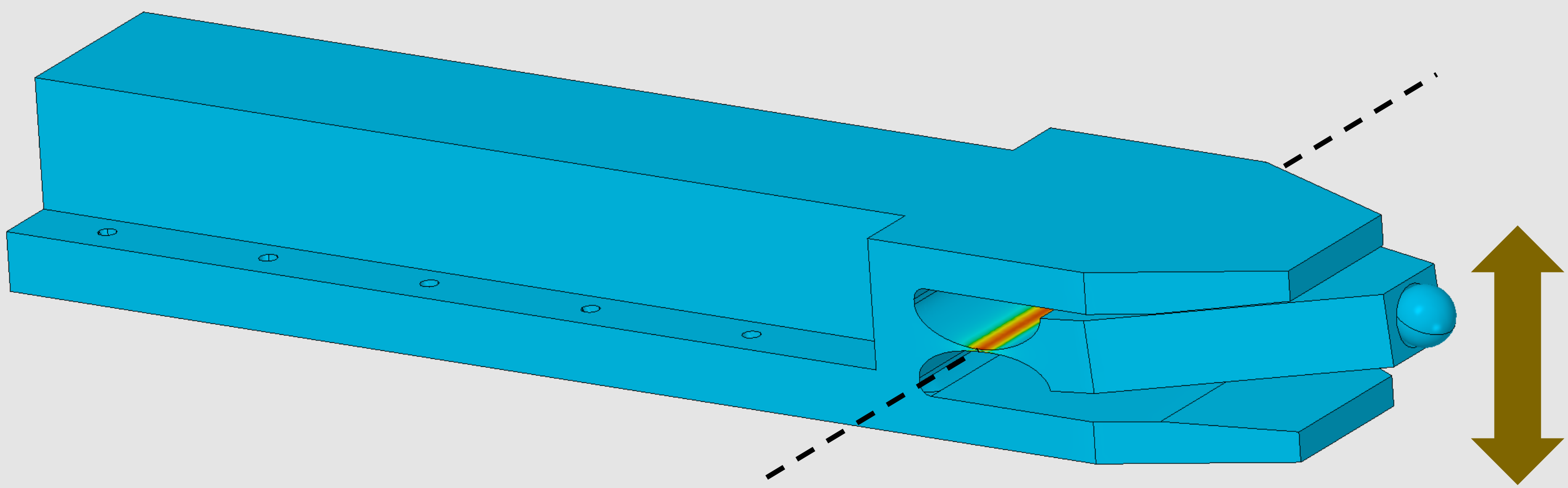
- What are flexures
  - A simple example
  - Manufacturing
  - Commercial solution
  - Advantages / Disadvantages
  - Kinematics with Flexures

- Applications for the Swiss Light Source
  - Monochromator for the VUV beamline
  - 2D linear high precision stage for the PolLUX beamline
  - Precision stage with delta kinematics for the OMNY endstation

What are Flexures – A simple example

Flexures are **flexible elements** that are **compliant in** all the **required directions** and **stiff in the other directions**.

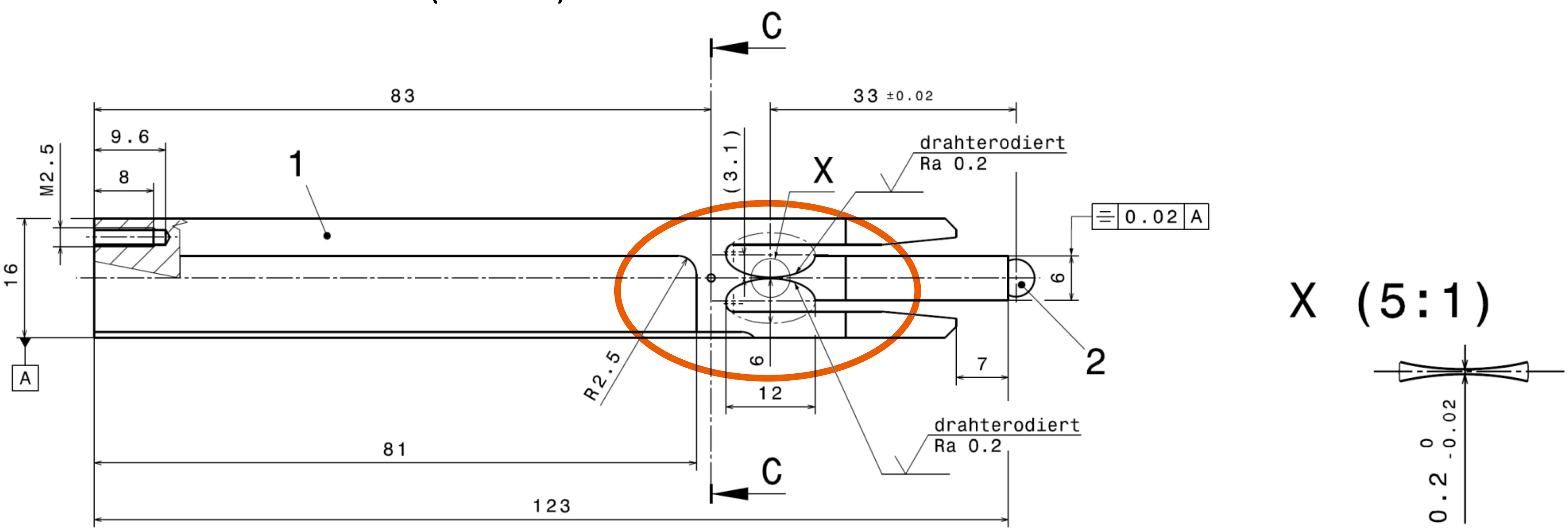
Example of a FEM calculation of a flexure hinge with **end stops** manufactured **from a single piece**. Maximum **stress** is shown qualitatively in red here.



How to produce Flexures

We typically use wire **electric discharge machining** (wire-EDM) to produce these flexures.

Typical materials:
aluminium 50 AlZnMgCu0.5 (3.4345),
titanium grade 5 Ti-6Al-4V (3.7165),
steel 316L X2CrNiMo 17-12-2 (1.4404),
steel 90MnCrV8 (1.2842)



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Commercial Flexures

Cross spring joints (Kreuzfedergelenke) or Flexural Pivots are available as a product.
Good introduction into flexures.

Advantages and Disadvantages of Flexures

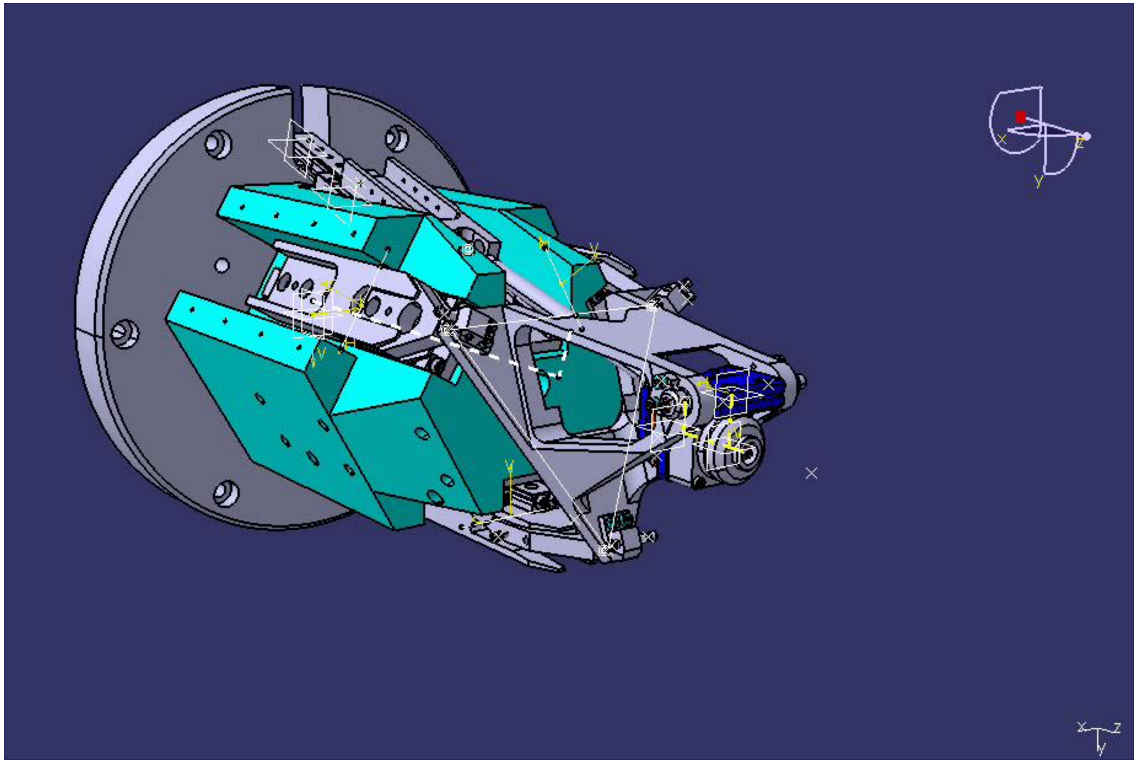
Pros
- Continuous and smooth movement even for very high resolution
- Friction less, no stick-slip effect
- Errors are repeatable and continuous
- Continuous relationship between applied force and displacement
- Wear free
- Simplified formulas for the commonly used flexures
- Finite element method (FEM) leads to good predictability

Cons
- Limited range for a given size and stiffness
- Parasitic movement
- Fatigue cracks could develop

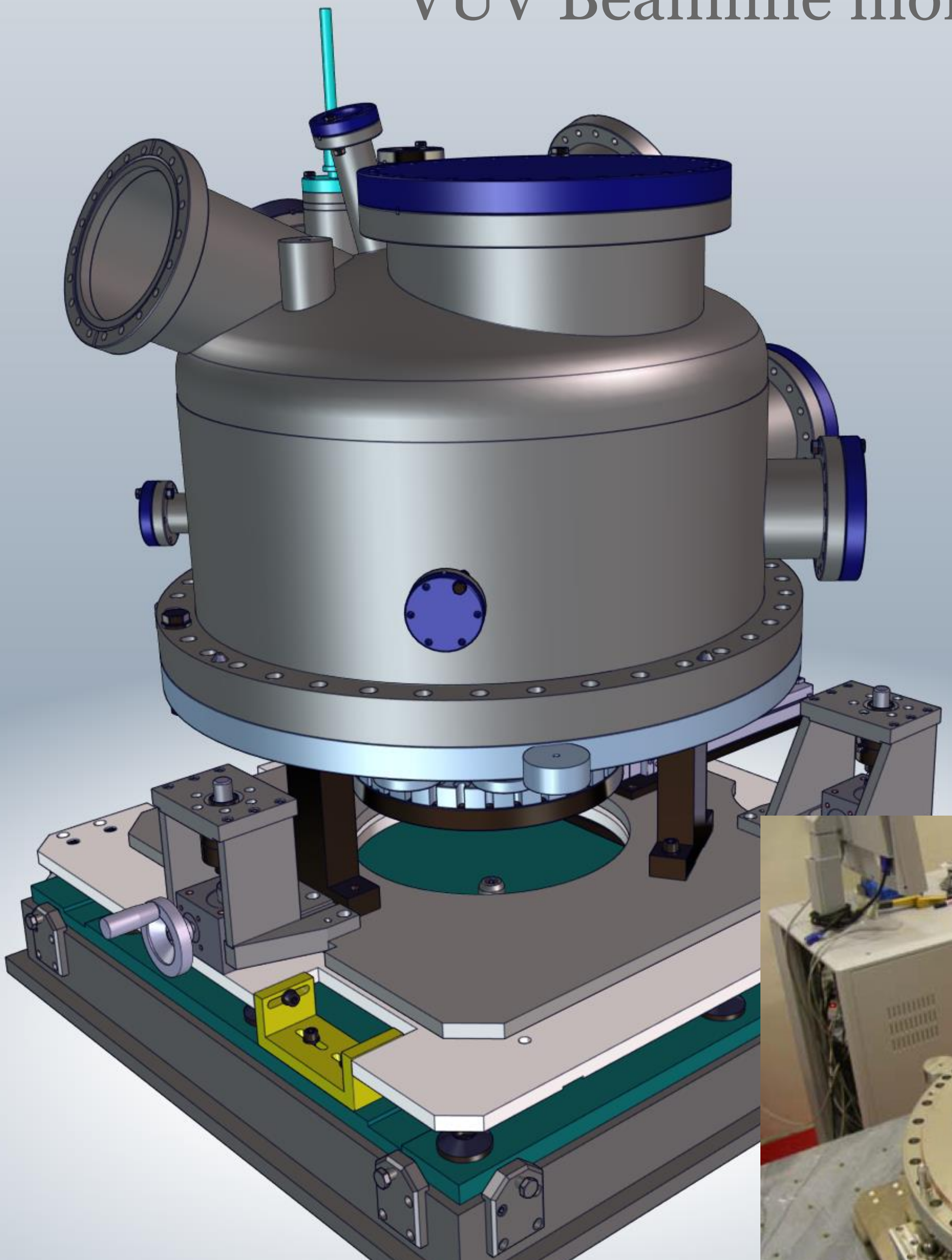
Flexure Kinematics - Examples

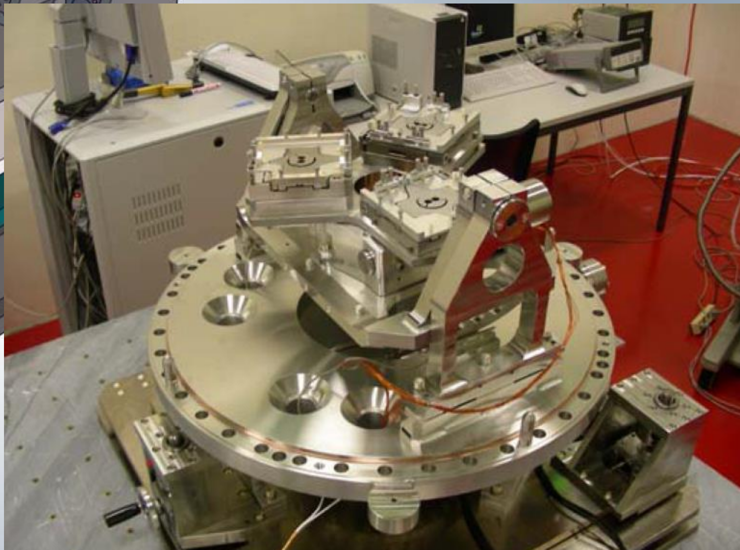
- Flexures with external rotation point
- Flexures used as a gearbox for rotation or linear movement
- Flexures as a linear or rotational bearing
- Flexures to compensate for parasitic movements of other components
- …

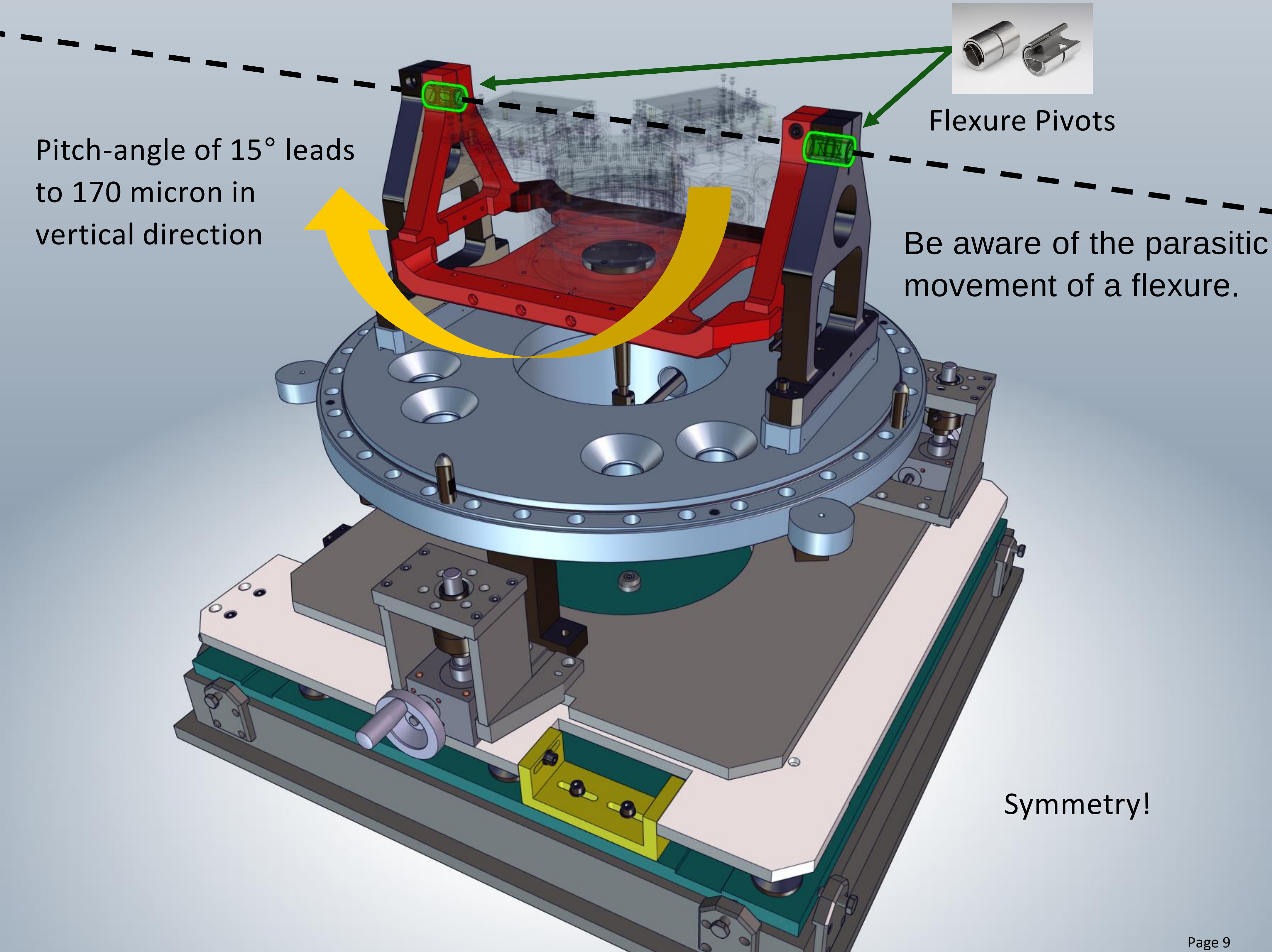
-> Countless combinations
in 3D are possible



VUV Beamline monochromator

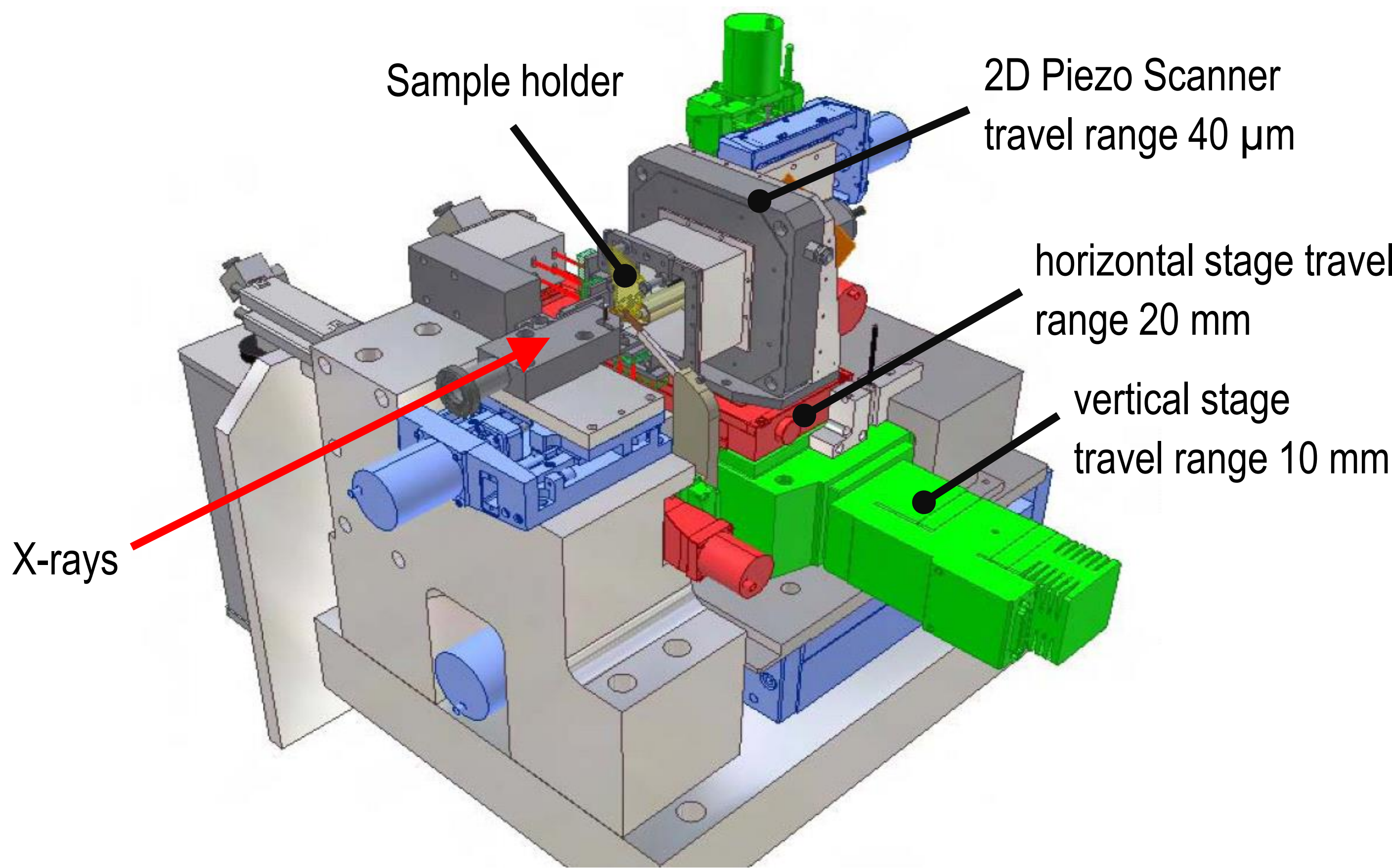





Flexure Pivots
Pitch-angle of 15° leads to 170 micron in vertical direction
Be aware of the parasitic movement of a flexure.
Symmetry!

Flexure Stage for the PolLUX Beamline

The PolLux Microscope uses 2D sample raster scanning in the X-ray beam to reach a measuring resolution below 10 nm. The existing horizontal and vertical spindle drives used ball bearings.



PolLUX Flexure Stage - Objectives

Previous solution: spindle drives with ball bearings.
Drawbacks to overcome with the new solution:

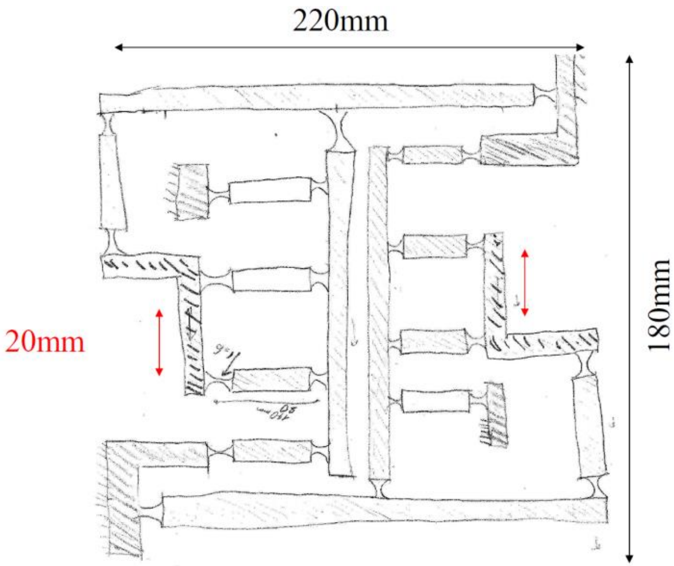
- non-repeatable errors

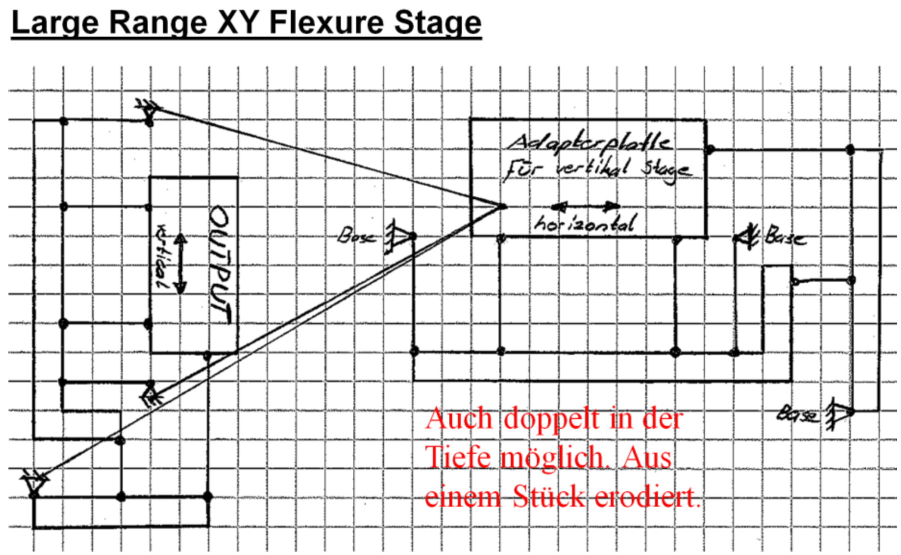
- lubrication in vacuum
- outgassing
- drift due to heat from stepper motors

Implement new design based on flexures

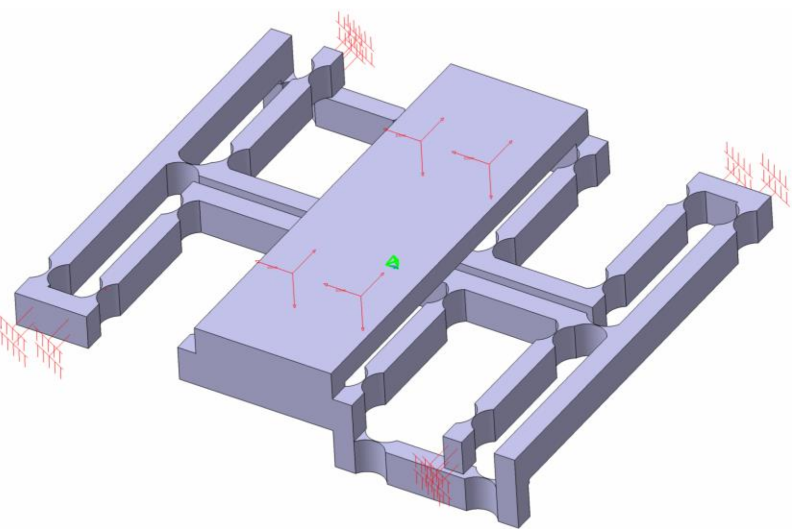
- minimal tilt errors
- reproducible error movements
- UHV compatible
- fits the existing instrument and its dimensions
- load 5 kg

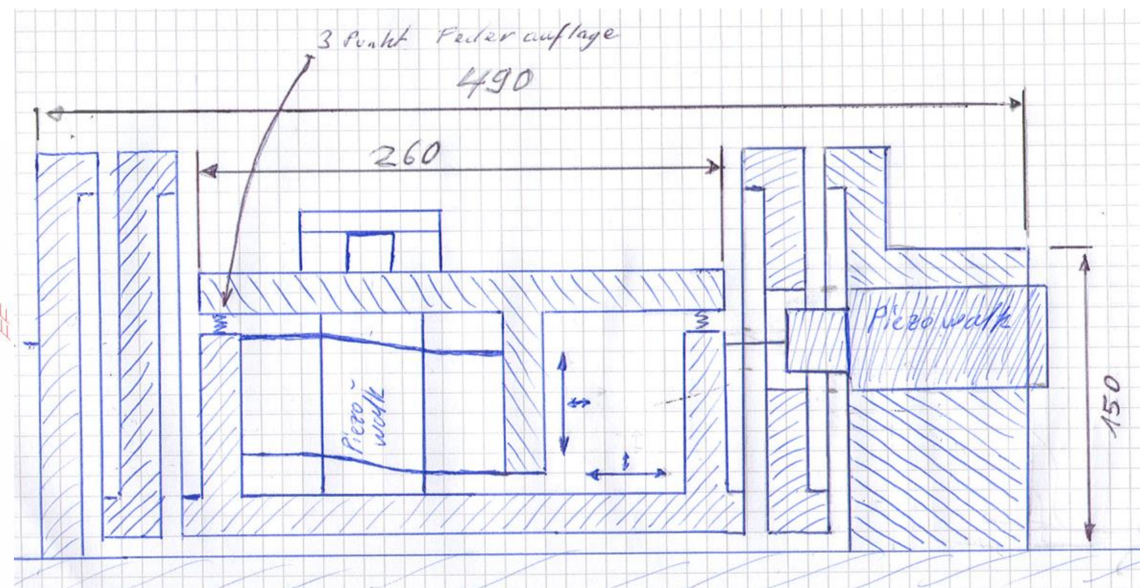
PolLUX Flexure Stage - Ideas



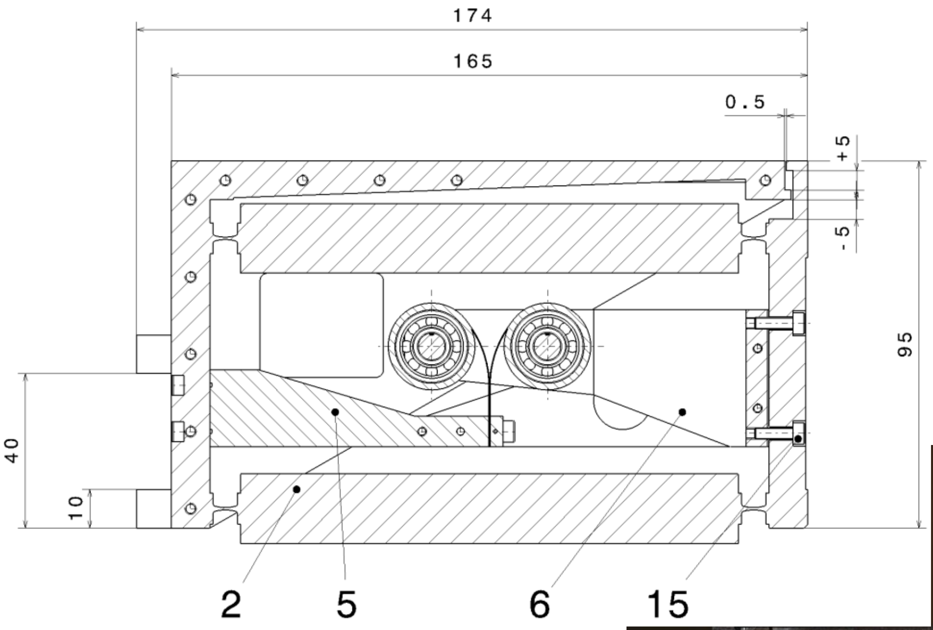


Forced guidance for intermediate stage





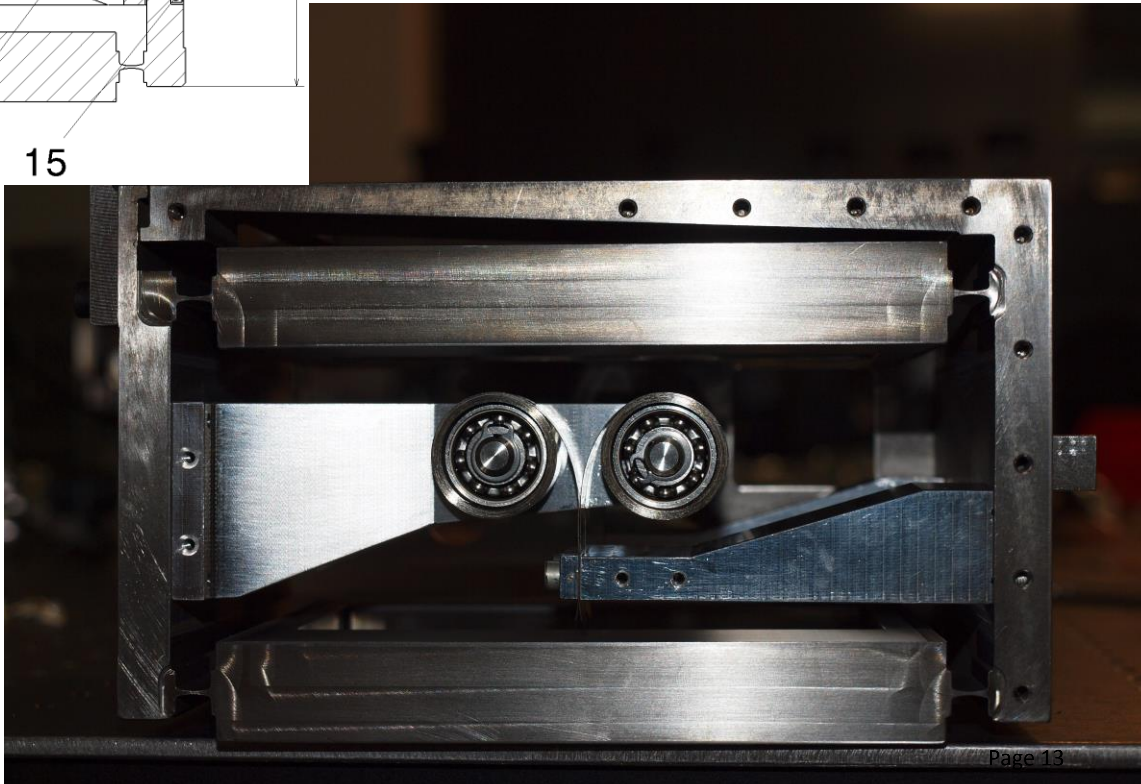
PolLUX Flexure Stage - height adjustment



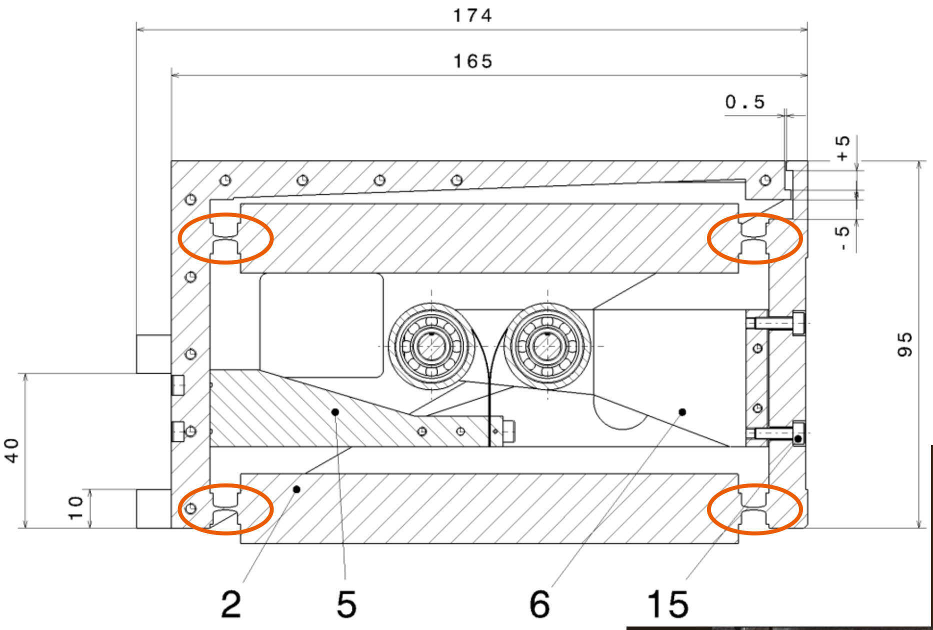
Custom design

Parallelogram flexure

vertical lift: **± 5 mm**



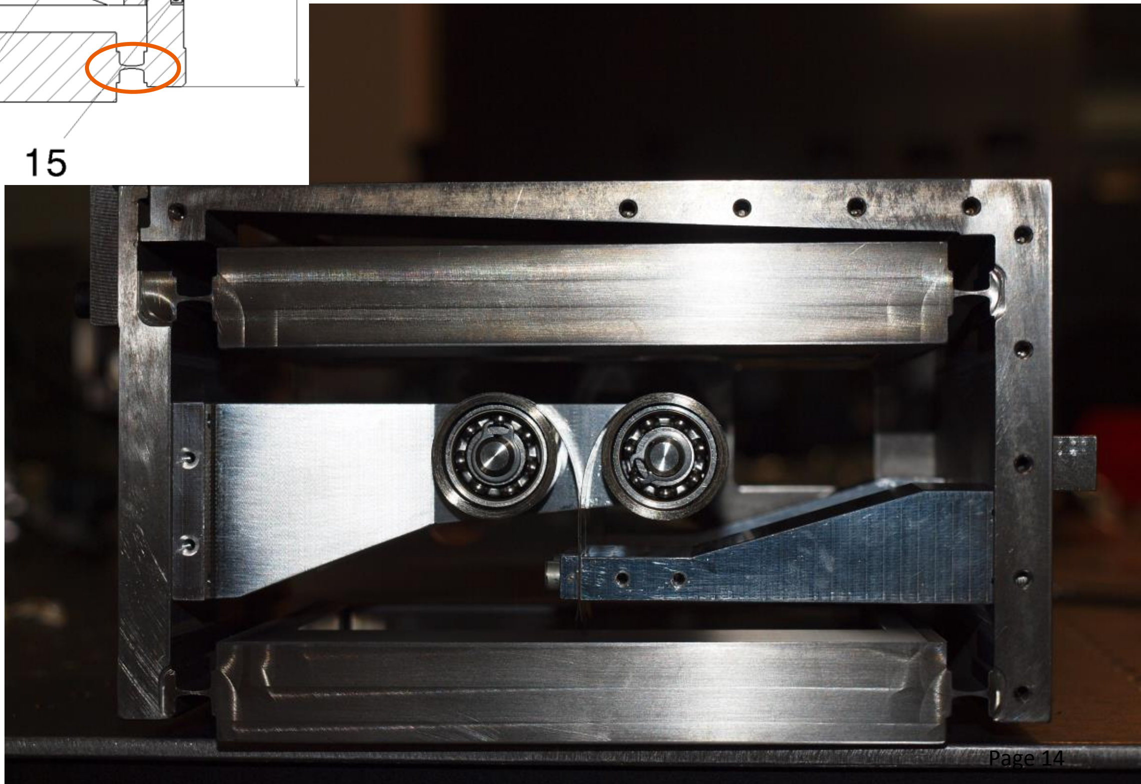
PolLUX Flexure Stage - height adjustment



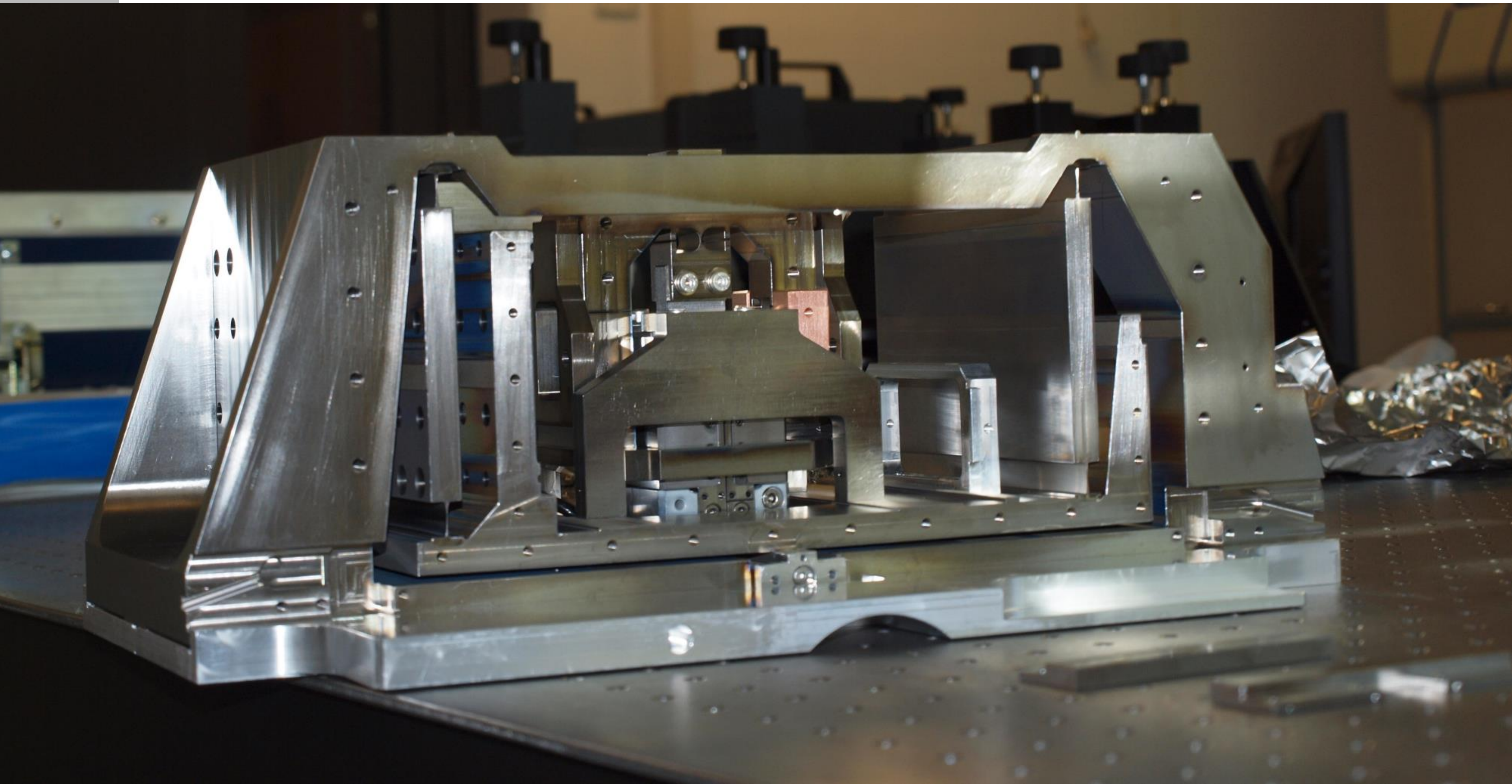
Custom design

Parallelogram flexure

vertical lift: **± 5 mm**



Flexure Stage for the PolLUX Beamline



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PolLUX Flexure Stage - Key Facts

custom design

horizontal stroke: **± 10 mm**

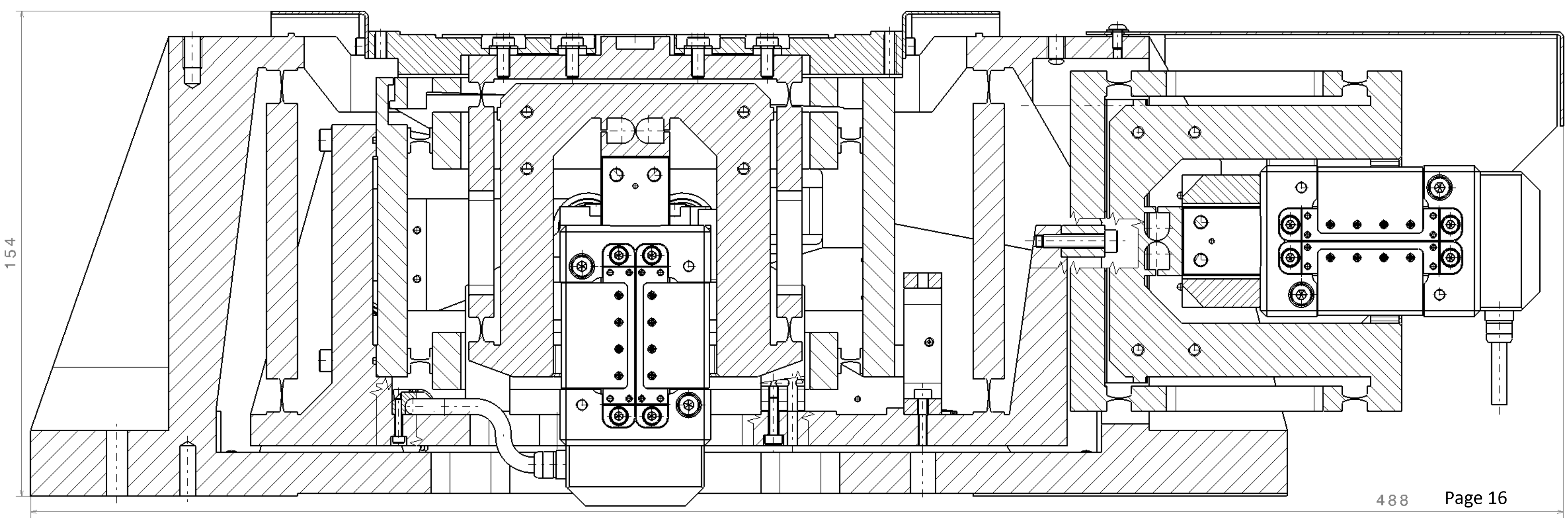
maximum load: **5 kg**

resolution (closed-loop): **5 nm**

tilt (full stroke): **<± 50 µrad**

tilt (over a distance of 200 µm): **<± 5 µrad**

resonance frequencies (at 1.5kg load):
119Hz / 142 Hz / 223Hz



PolLUX Flexure Stage - Linear coupling

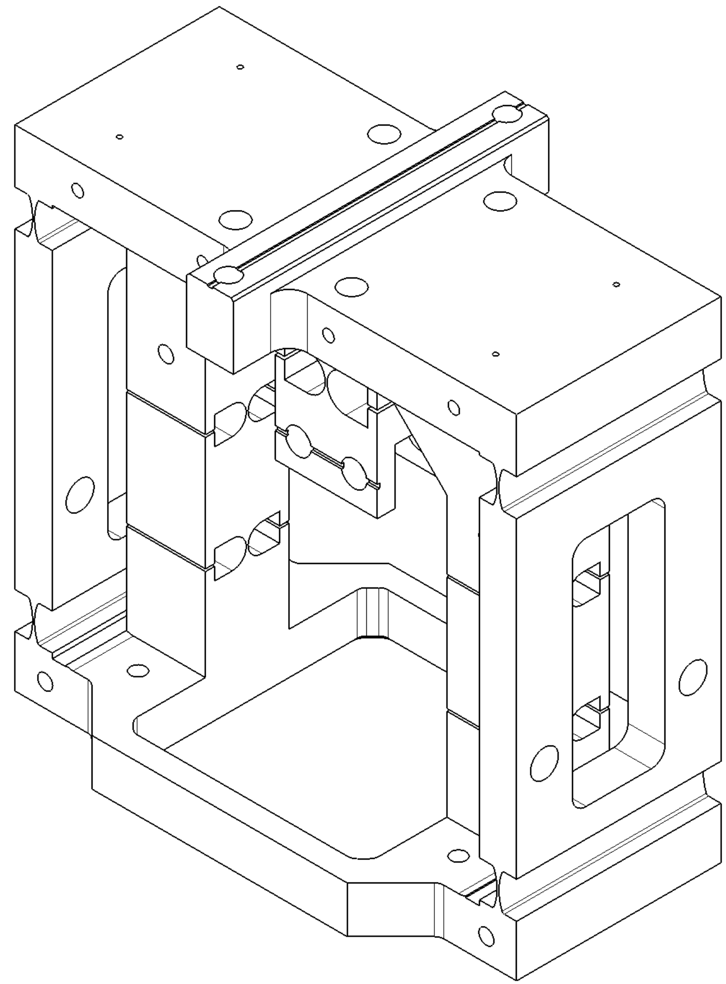
For the connection of the motor, a linear coupling was required.

- High stiffness, but only in axial direction
- Needs to fit in the given space constraints
- No play / backlash
- No friction

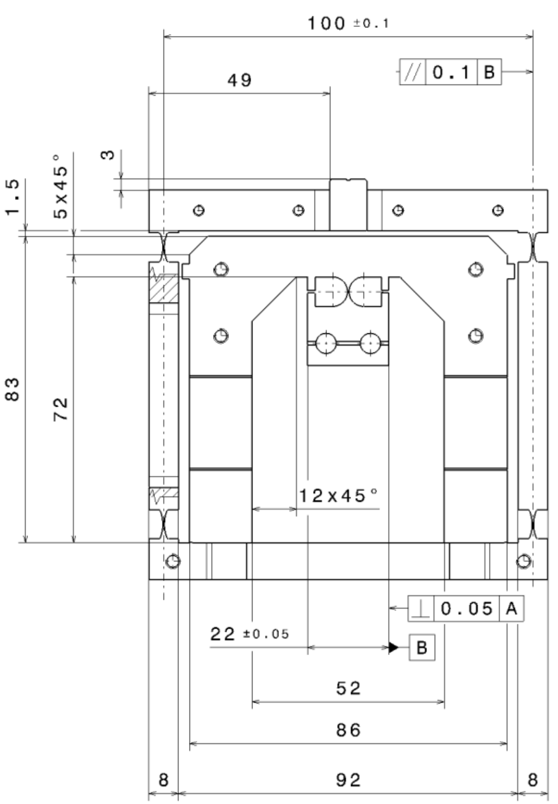
-> Custom design

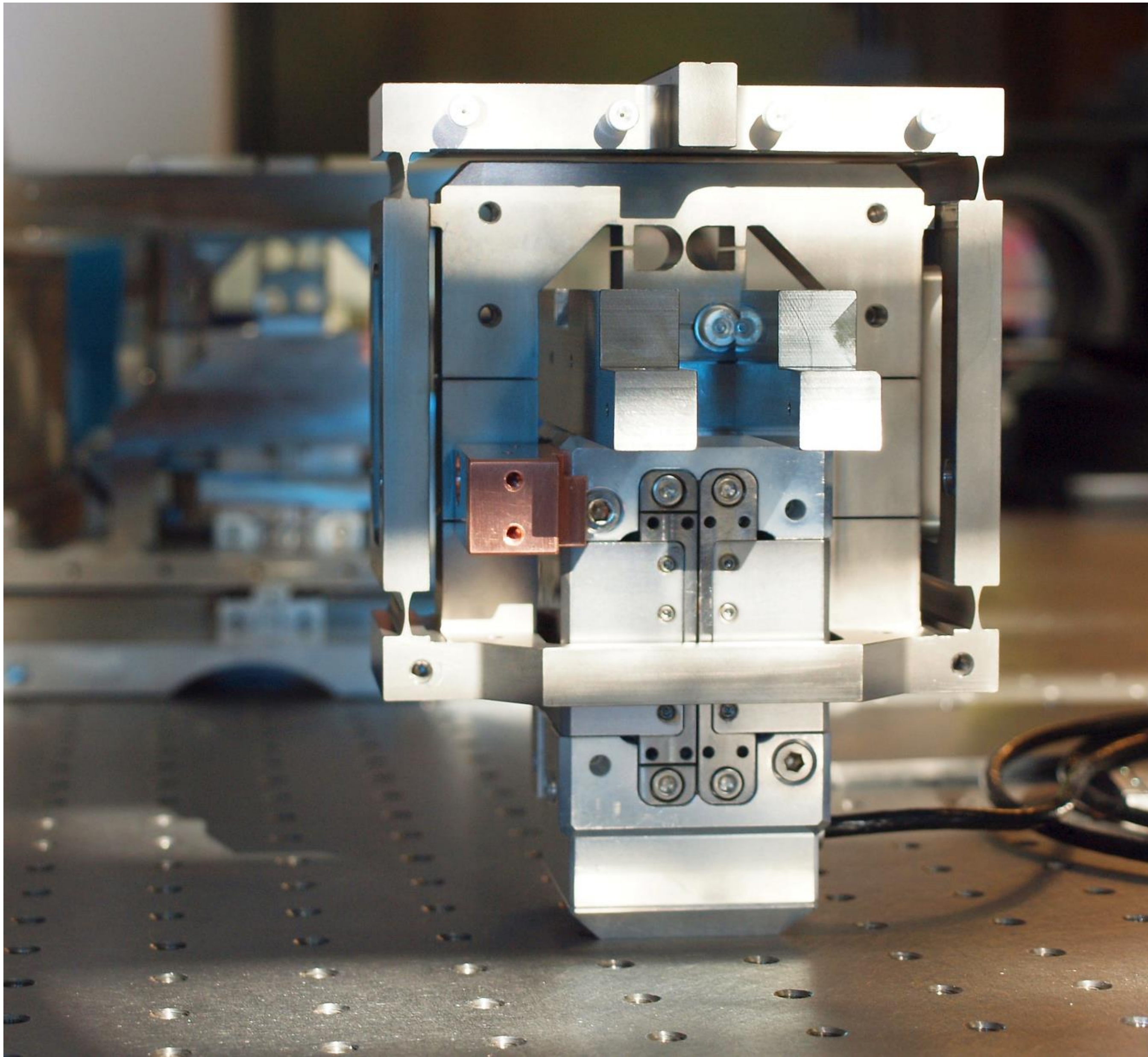
Key facts:

- Machined from one piece of grade 5 titanium
- Wire EDM used for flexures
- Solution annealing and artificial ageing
- Flexure Thickness: 0.4 mm
- Weight: 615 g

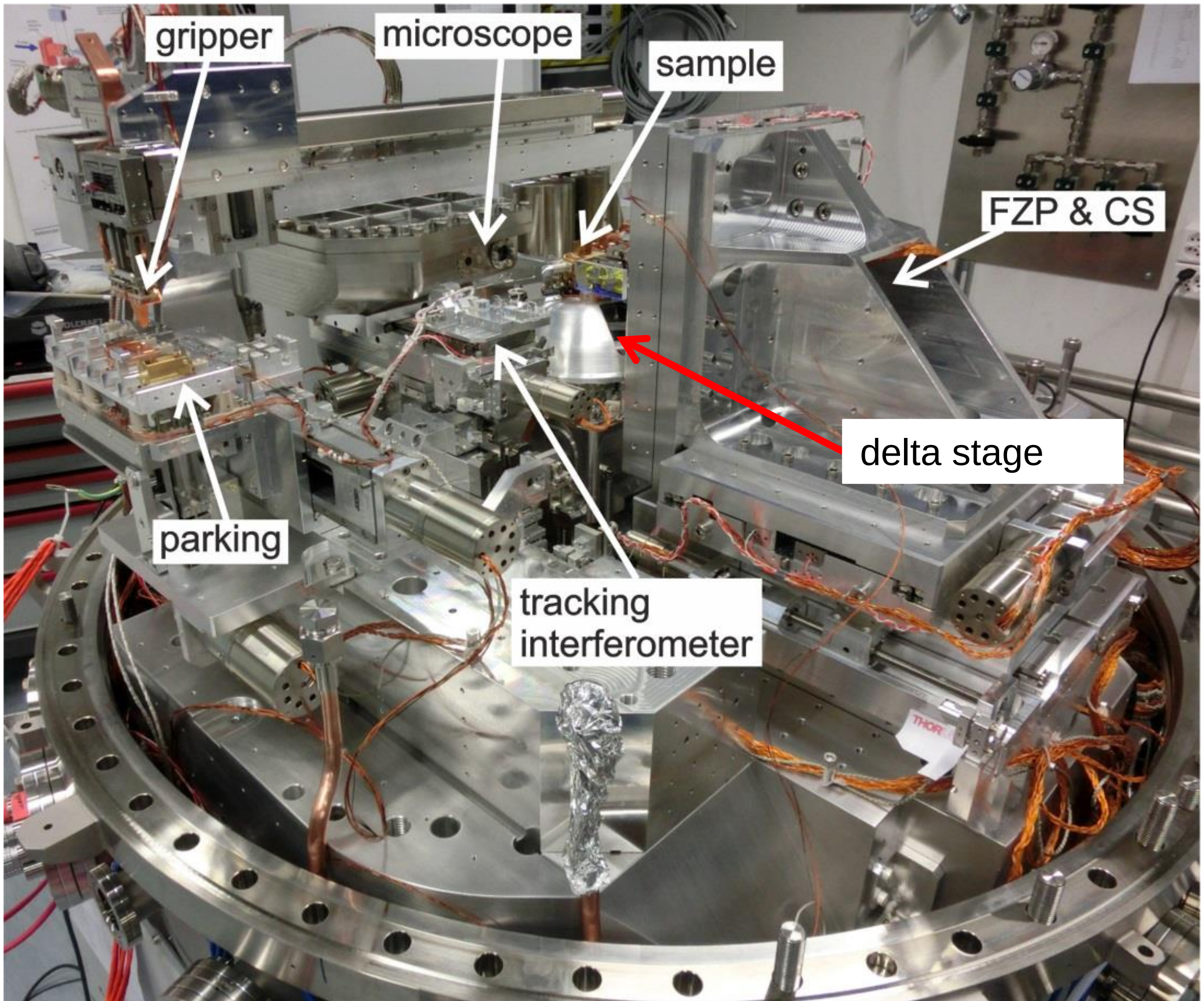


PolLUX Flexure Stage - Linear coupling





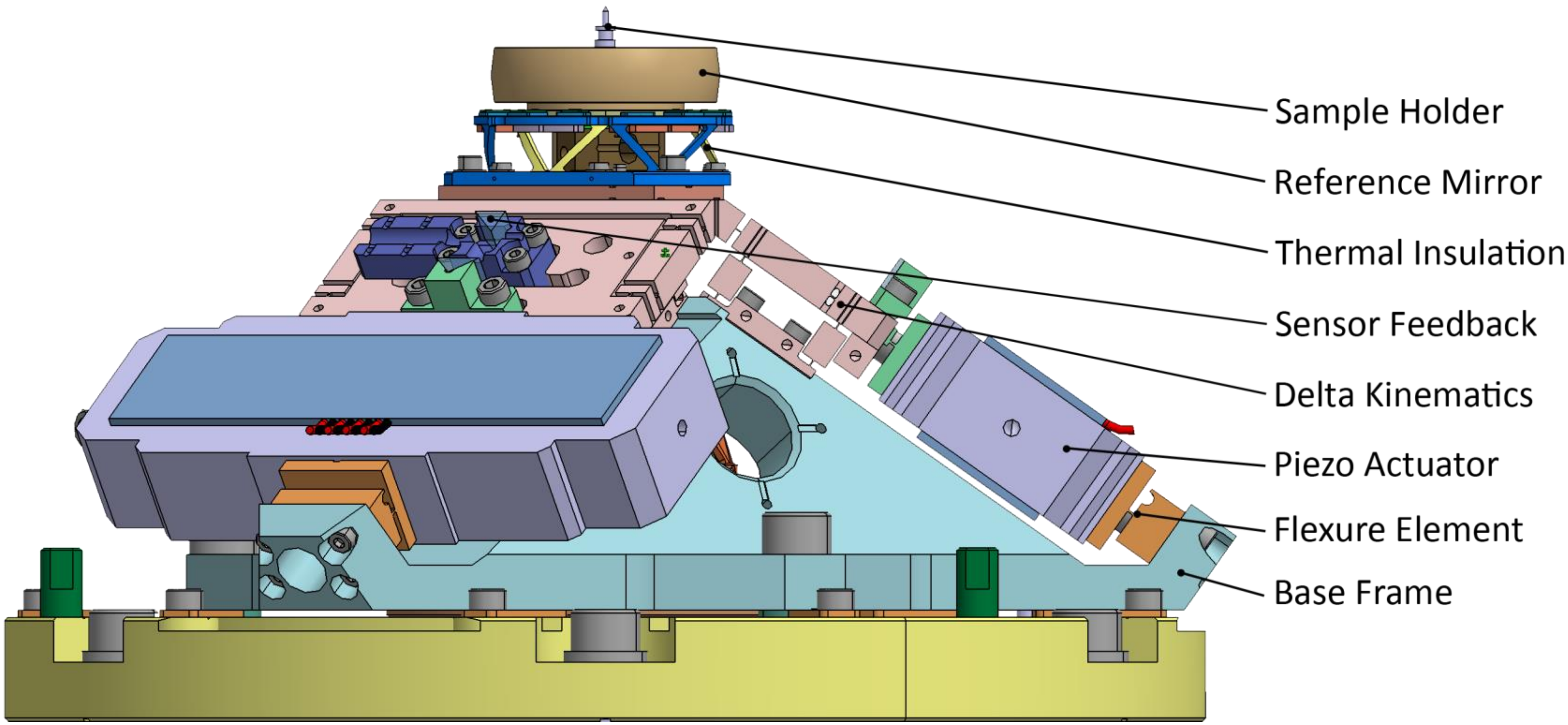
OMNY - Delta Stage



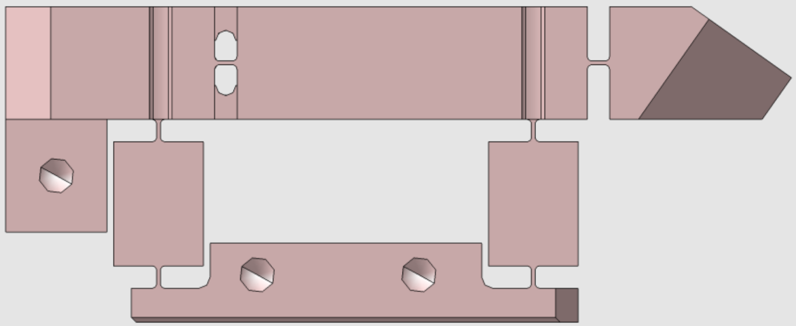
OMNY Delta Stage - Requirements

- **Piezo stage** developed and optimized for **scanning x-ray microscopy**.
- The stage provides **three translational degrees of freedom**.
- **Travel range** of **400 micrometre** in each direction.
- Positioning accuracy is achieved via **closed-loop laser interferometry**.
- Sample directly mounted on reference mirror to **minimise abbe errors**.
- Optimised for **high stiffness**
- **Angular error** motions **below twenty µrad**.
- Scans with a **resolution in the nanometre range**.
- **Positioning times below thirty milliseconds** for high scanning rates.
- Clear aperture in the centre used for the **continuous flow cryostat**.
- **Vacuum** compatible down to **10^{-8} mbar**.
- **Closed loop resolution around 1 nm**.

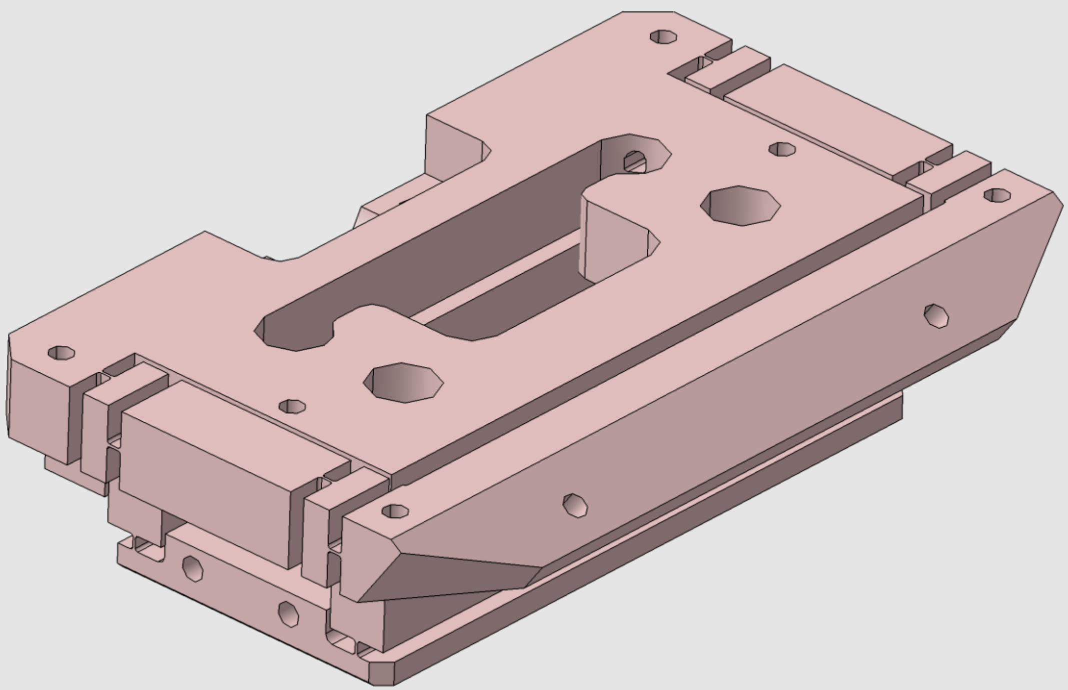
OMNY Delta Stage with its components



OMNY Delta Stage Flexure Design

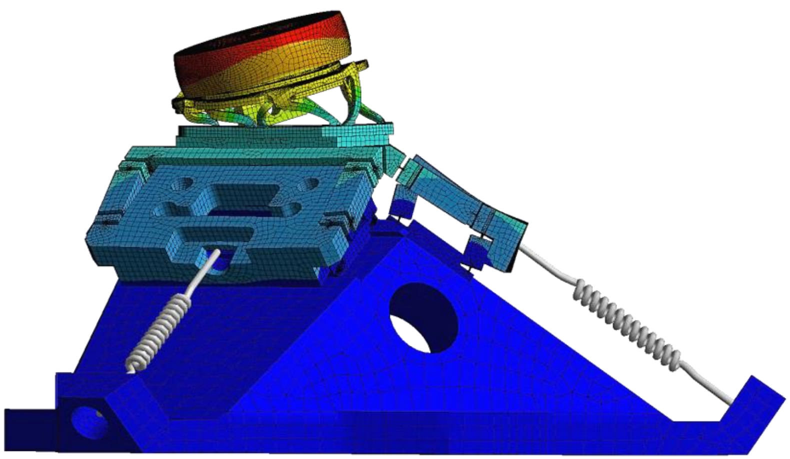


Comparison of **multiple flexure designs** and angular orientations to **find optimal trade-off** between nominal **travel range**, **high stiffness**, **repeatability** and **minimal roll and tilt errors**.



OMNY Delta Stage Natural Frequency and Specs

Optimisation of natural frequency of the piezo stage itself verified with FEM calculations.



First natural mode at a natural frequency of 450 Hz.

- **Rotational error motion:** < 20 µrad
- **Range in each axis of the coordinate system:** ± 0.2 mm
- **Positioning time:** 15 ms
- **Max. temperature of actuators:** 50 °C
- **Vacuum conditions:** < 10^{-8} mbar
- **Closed loop resolution:** 1 nm
- **In-position stability:** 1.7 nm SD
- **Piezo stage weight:** 2.8 kg
- **Outer diameter:** 182 mm
- **Height with reference mirror:** 97 mm

My thanks go to

All my colleagues who made the examples I have shown you possible.

Thank you for your attention.

I am looking forward to an **engaging discussion** about possible use cases in neutron instrumentation.