PETRA IV.
NEW DIMENSIONS

PETRA IV Alignment overview

IWAA 2024 - SLAC

Jana Barker (MEA2)
Menlo Park, 8th October 2024

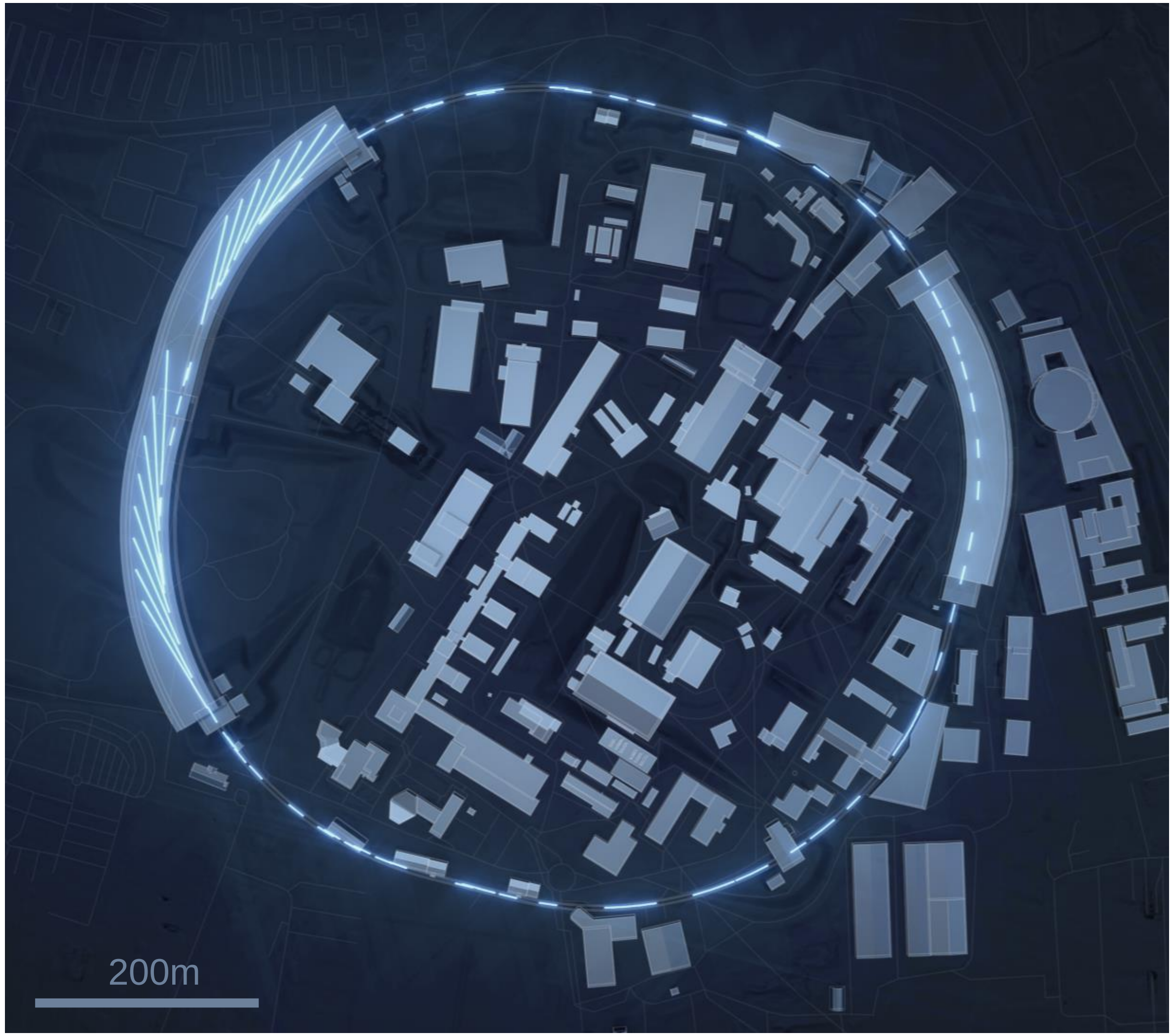
HELMHOLTZ

DESY.

Introduction

Petra IV

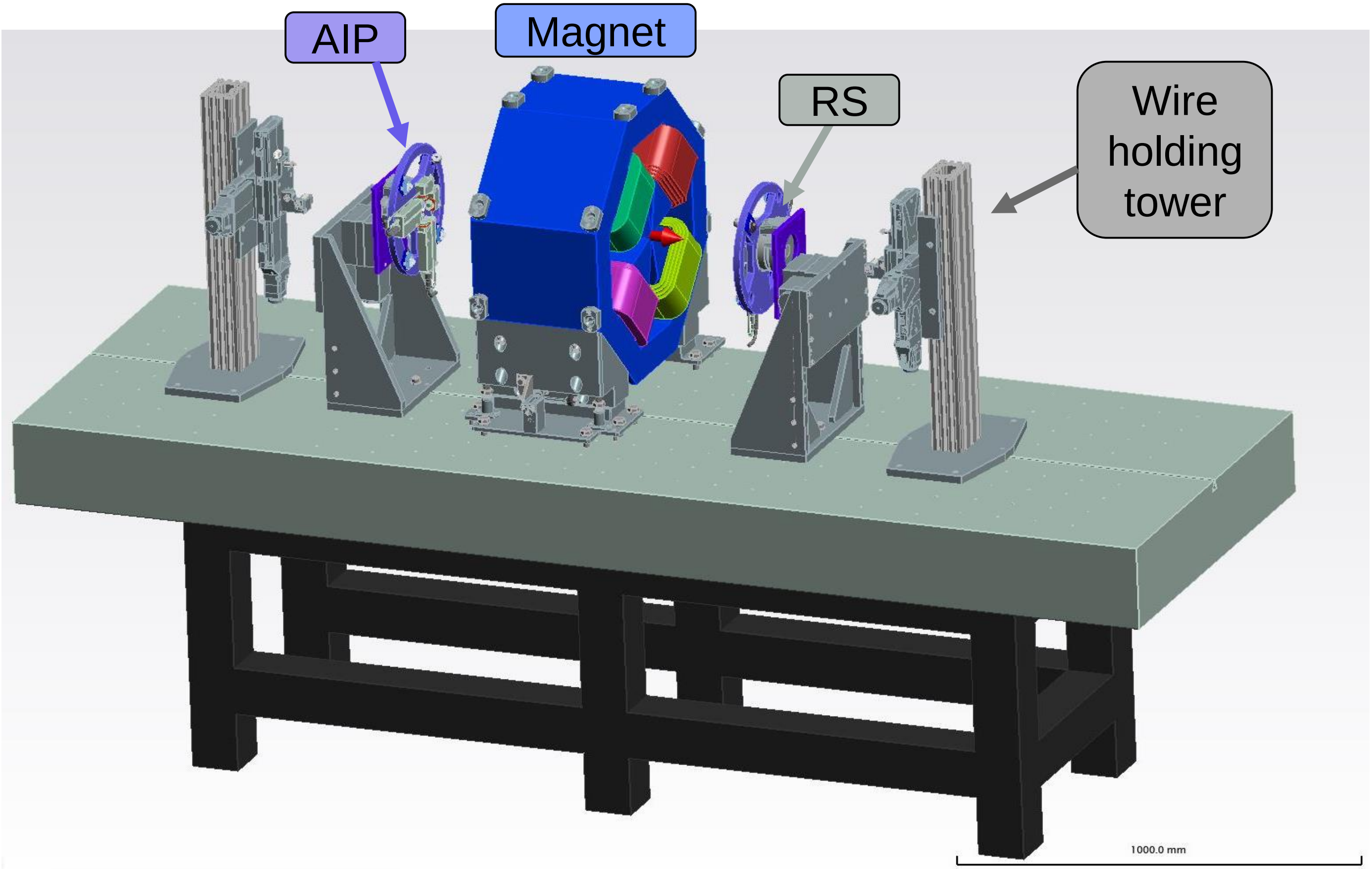
- TDR ended at the start of 2024 → Prototyping phase
- Uses mostly existing tunnels, new experimental hall
- Over 3000 magnets to fiducialize (2659 resistive)
- **$\sigma_{Magnet2Magnet}$ = 30 µm, $\sigma_{Girder2Girder}$ = 100 µm**
  - Definition: maximum size of the semi-major axis of the error ellipsoid at ~p=0.68 (1σ)
- Fiducialization with
  - Laser Tracker
  - Photogrammetric
- Instrument pillar design
- Automatization and software



Fiducialization

Resistive Magnet Measuring Bench

- Two main goals during development:
  - Uncertainty ≤ 15 µm
  - Automatization
- Bench components:
  - 2 wire holding towers with perpendicular linear stages
  - 2 stands each holding a rotational stage (RS) with alignment interface plate (AIP) axially traversed by the stretch wire
  - Maybe: linear stages between AIP and RS?
- No magnetic or magnetizable materials usable

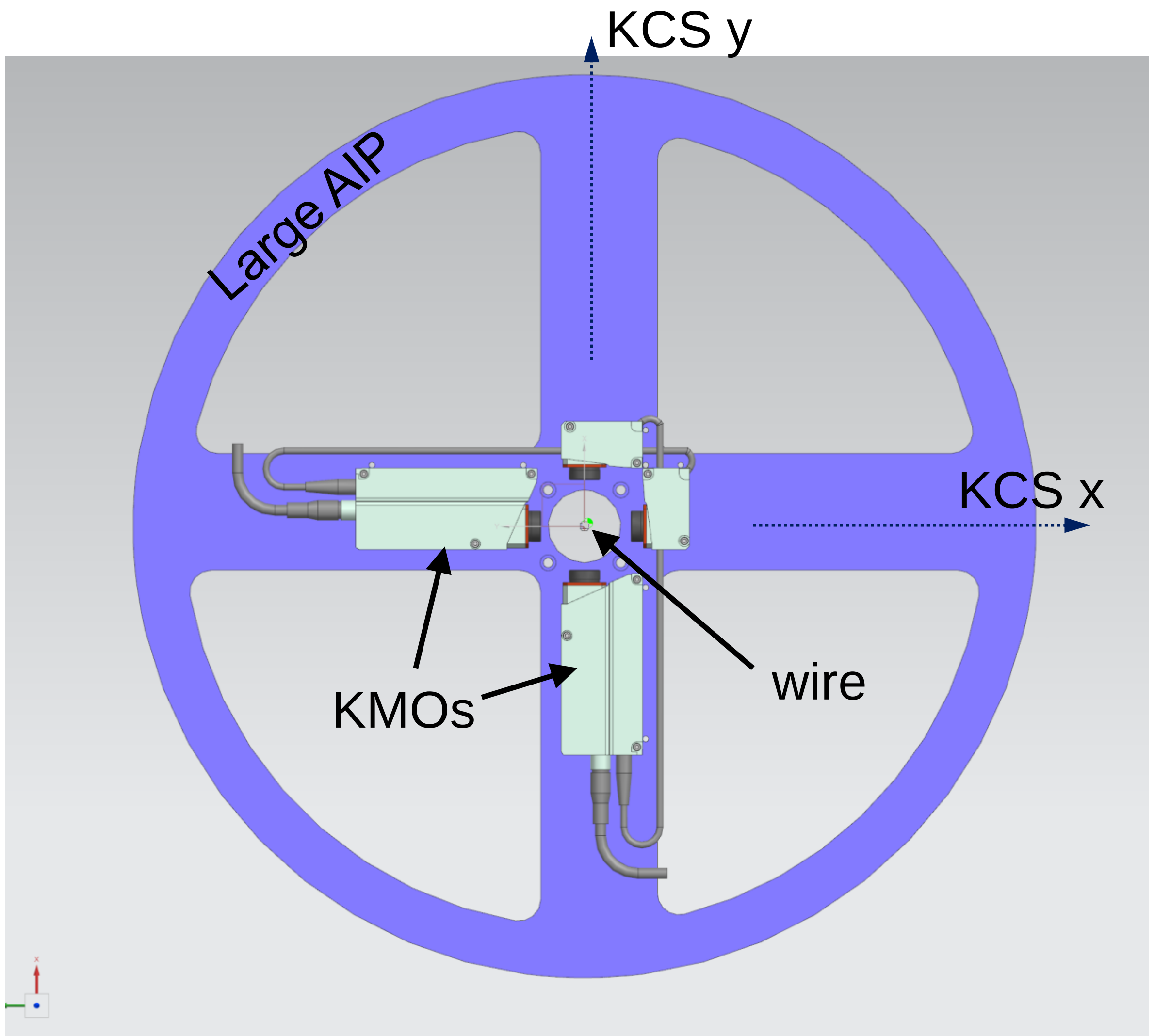


Resistive Magnet Measuring Bench

Daniel Thoden

Fiducialization

Alignment Interface Plate

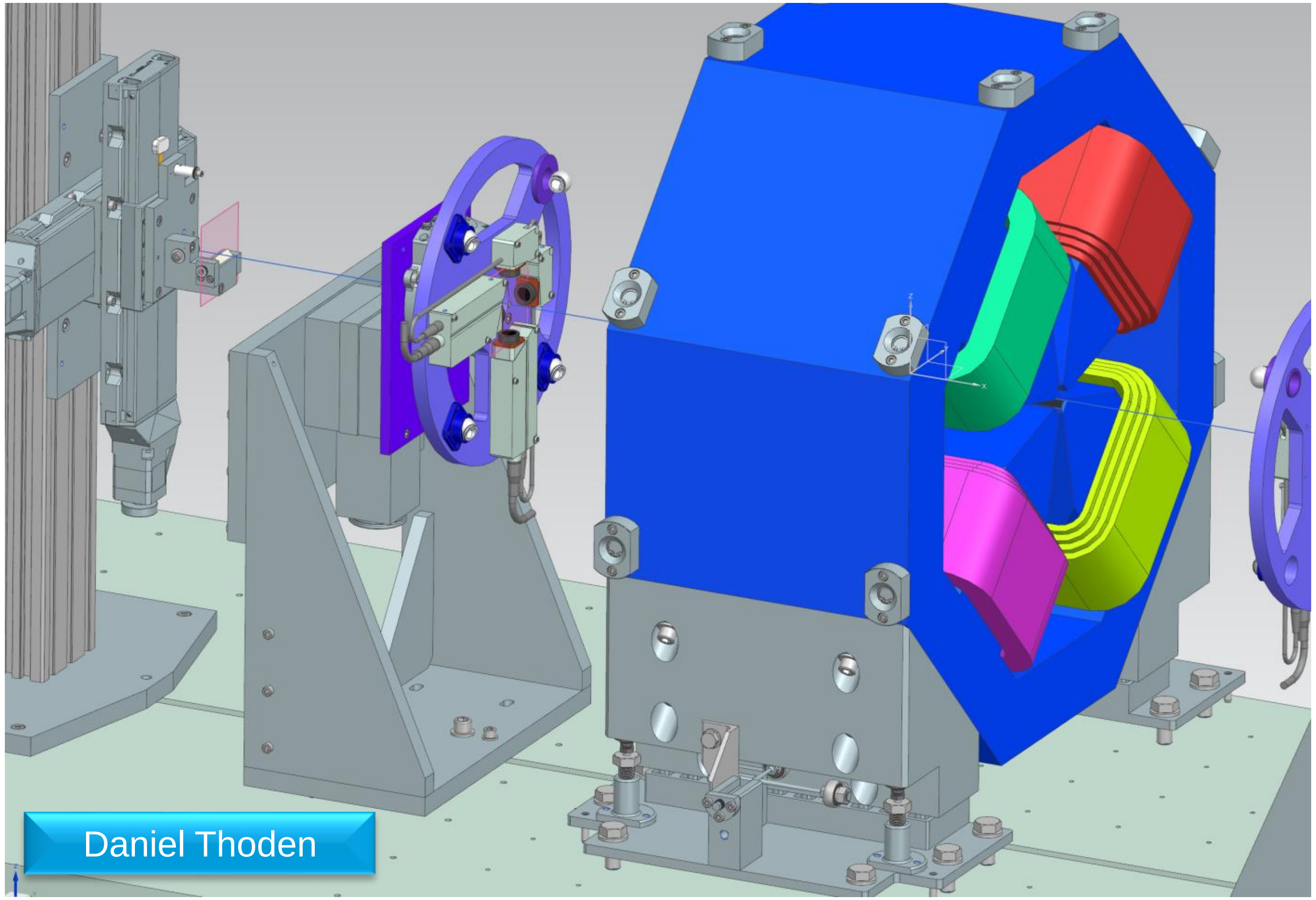


- AIP holds two (roughly) perpendicular Keyence laser optical micrometers (KOMs)
- Each KOM measure one coordinate axis
  - creating a roughly perpendicular CS: "KCS"
- KOMs measure the wire position as the stage rotation
- KCS are referenced to the AIP fiducials during stand calibration
- The relationship of KOMs to AIP fiducials is characterized by a non-changing angle

Fiducialization

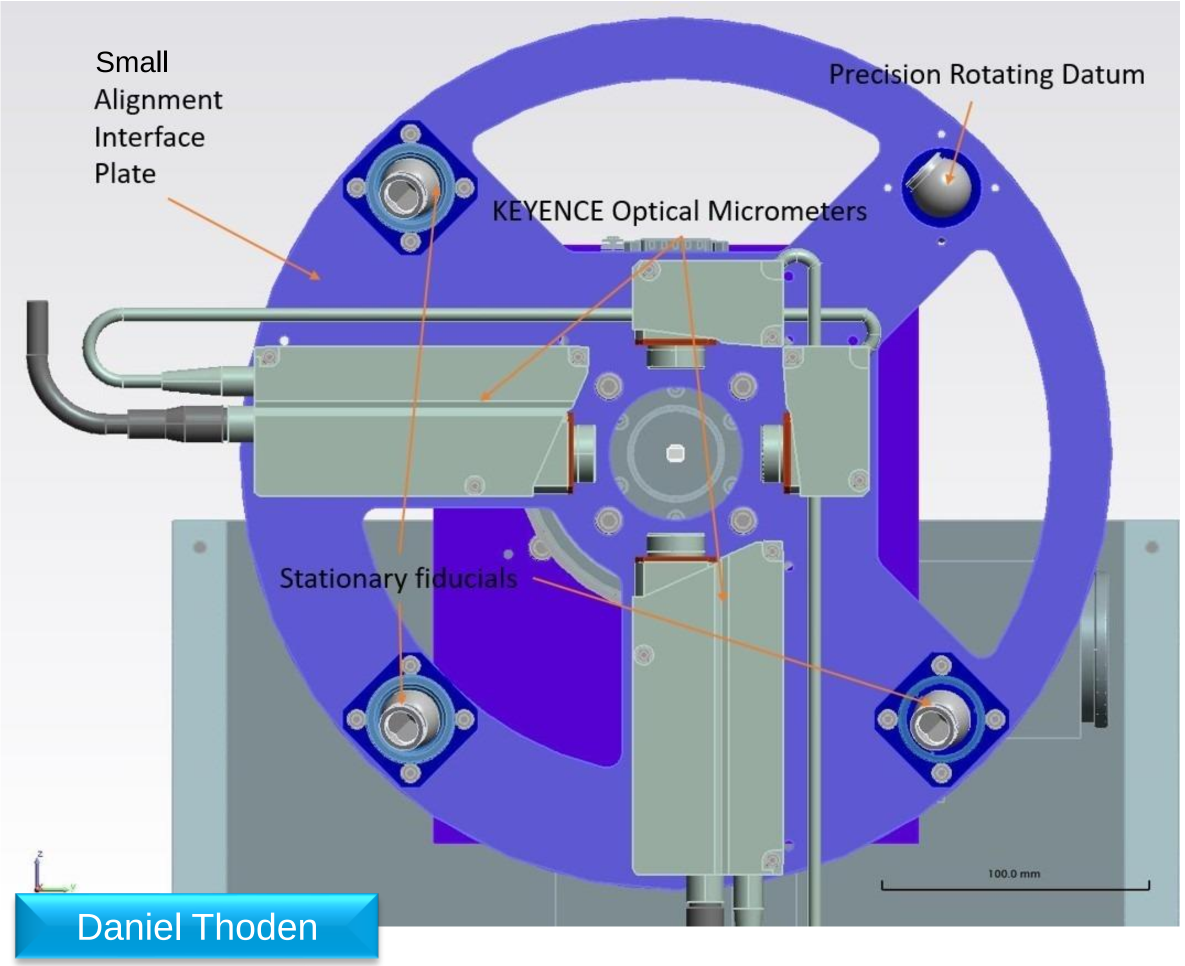
Measurements of the Magnetic Axis

- Initial AIP position measured using all fiducials
- AIP rotates; KOMs measure the wire position, fiducial(s) are measured by a method of choice
- Centre of rotation and the centre of the circle created by the measurements of the are coincident
- Magnet coordinate system is then determined:
  - X: the line between two wire positions
  - Z: a Roll angle vector in KCS (not certain yet)
  - Y: complementary to create Cartesian CS
  - Origin by measurements of pole tips



Fiducialization – Laser Tracker

Measurements



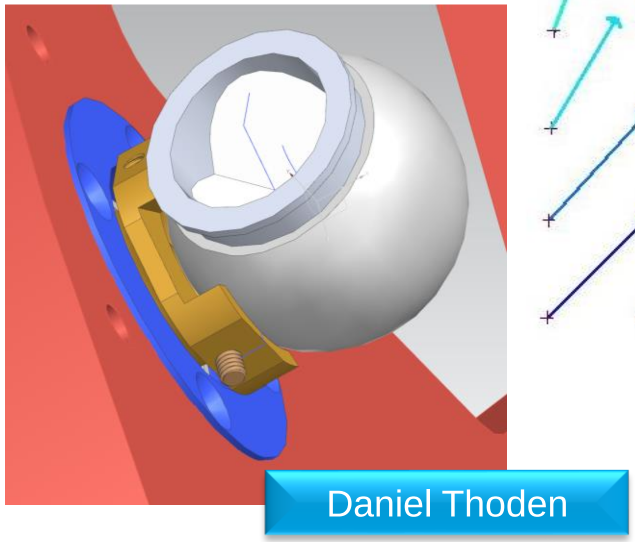
- AIP for laser tracker has the precision rotating datum (PRD)
- PRD is weight with a pendulum,
  assuring a consistent pointing to the laser tracker for automation; no manually rotating SMRs
- Stationary fiducials are 3 point of contact nests with a securing ring
- PRD enables non-experts to perform referencing with automation
- 72 points = every 5° in order to achieve $\leq 1\ \mu m$ using uncertainties from previous experience with AT960:

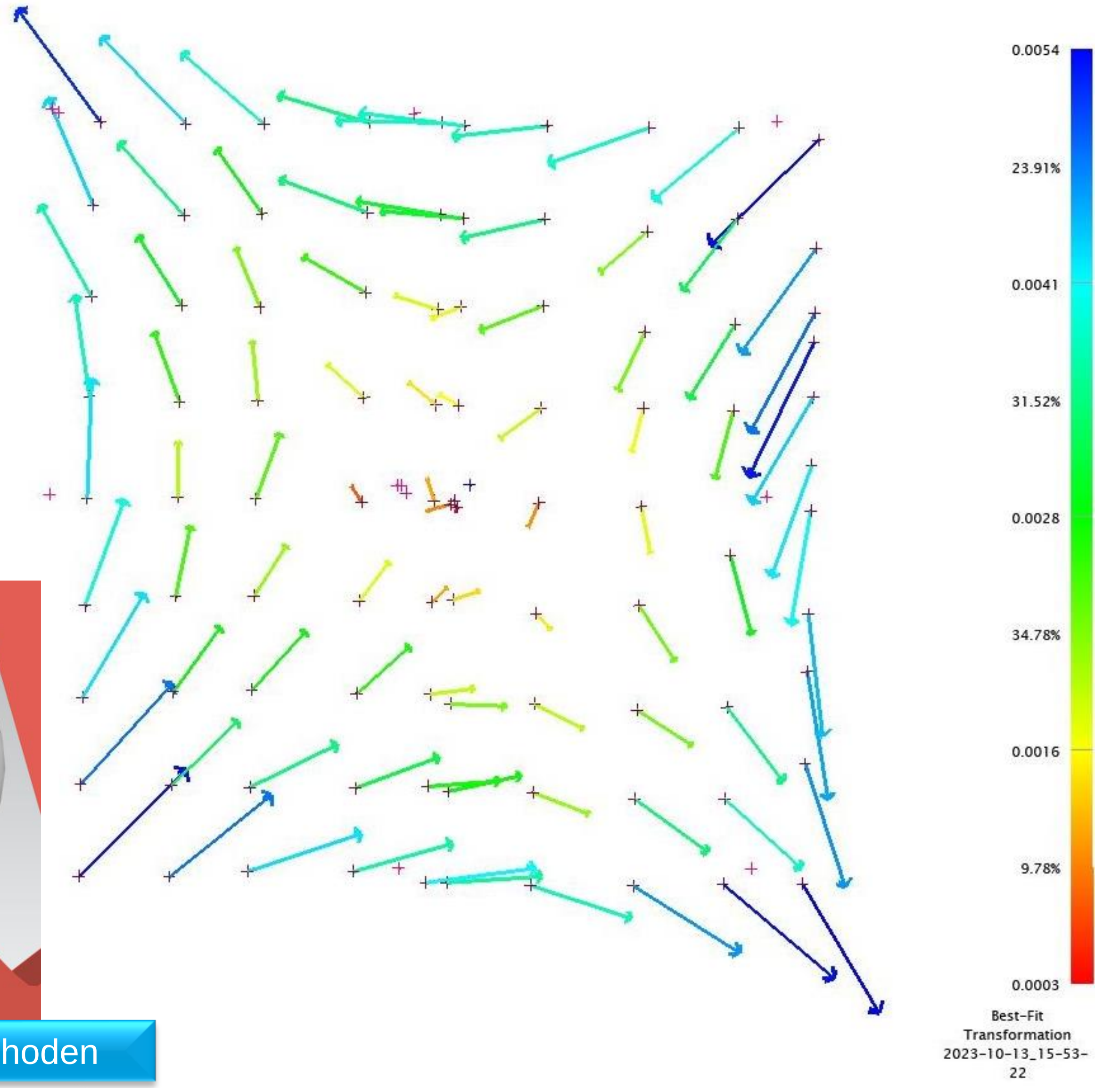
Quantity	Uncertainty
Horizontal angle	0.11 mgon
Zenith angle	0.42 mgon
Slope distance	4 µm + 1 ppm

Fiducialization – Laser Tracker

Calibration Procedure

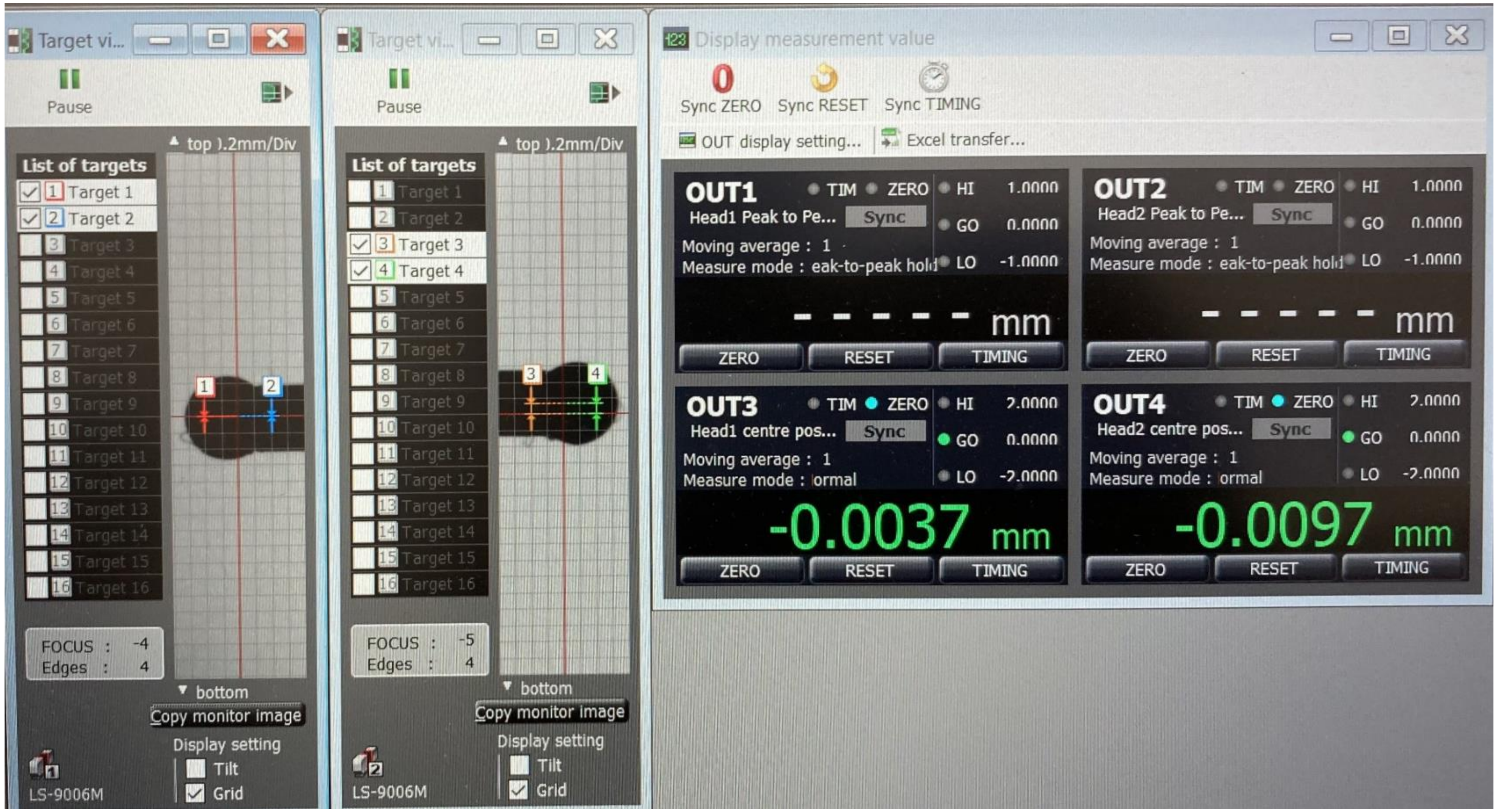
- The whole stand assembly is measured – all imperfections can be mathematically corrected
- The same points will be measured by CMM and KOMs
- An affine transformation matrix's parameters will be found using LSM
- KOMs measurements will be orthogonalized
- PRD will be gently locked in place during the calibration (for each position) and measured with the CMM probe if the precision of the rotation will not be accurate enough





Fiducialization – Laser Tracker

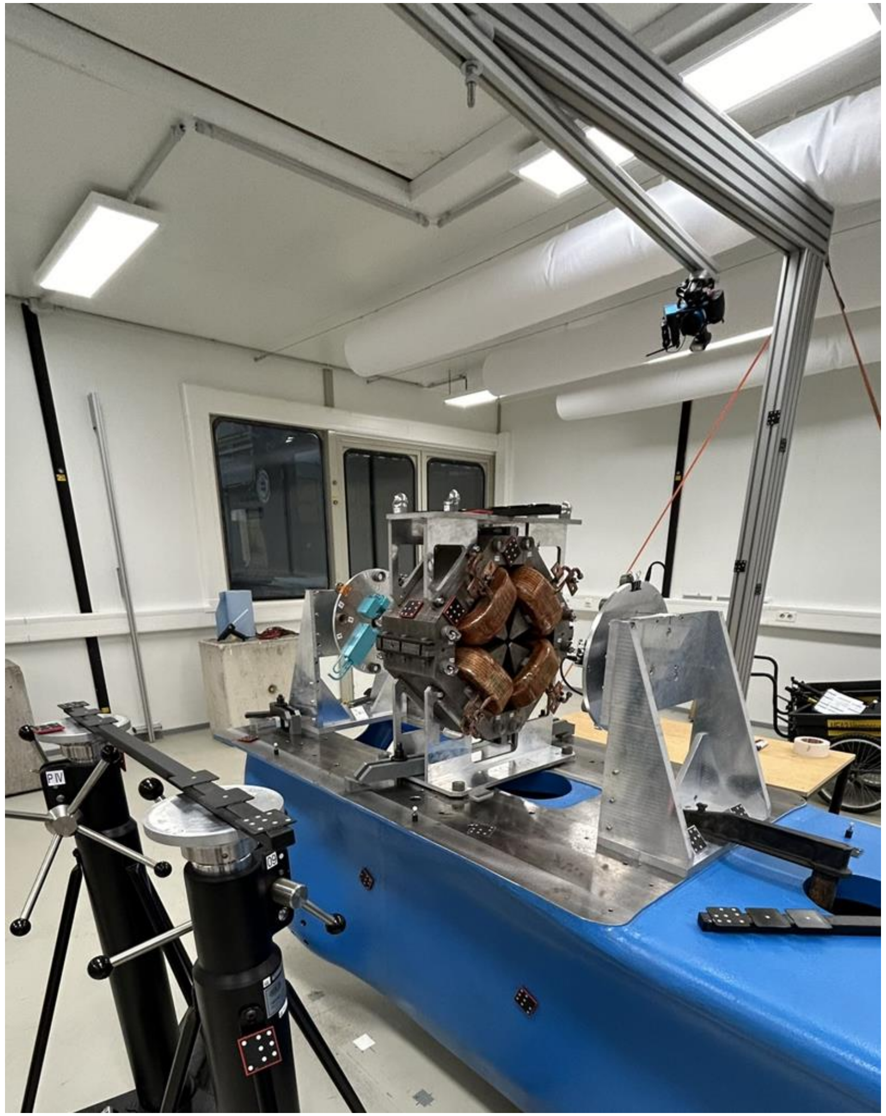
Calibration Procedure – Proof of Concept



- Proof of concept for calibration procedure has been successfully performed
- Measurements have to be done to the shaft of the tactile probe as the KOMs have better results
- Changing the color of the shaft did not change the accuracy
- Calibration must be streamlined compared to the PoC

Fiducialization – Photogrammetry

Proof of Concept



- Imaging AIP from a circular path above the measurement bench
- A large frame with the camera mounted on a rotating beam spanning over the magnet
- Camera height above magnet is ~1.5m
- Calibration method depends on the fiducials of choice
- Performed with GSI's Nikon 700D (50 µm version)
- PoC succesful, in all results reached the accuracy of the camera

Fiducialization - Photogrammetry

The Measurements and Proof of Concept Results

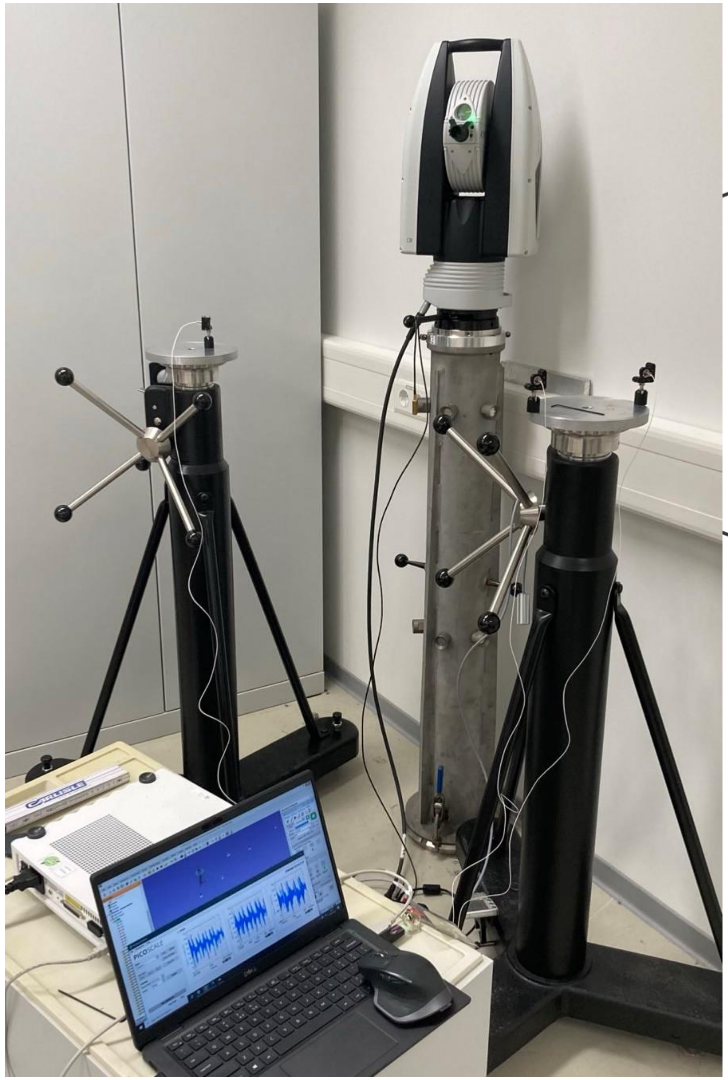
- After initial measurements, larger plates were manufactured
- During first measurements we experimented with fiducial positions
- 2 more sets were measured using the larger plates

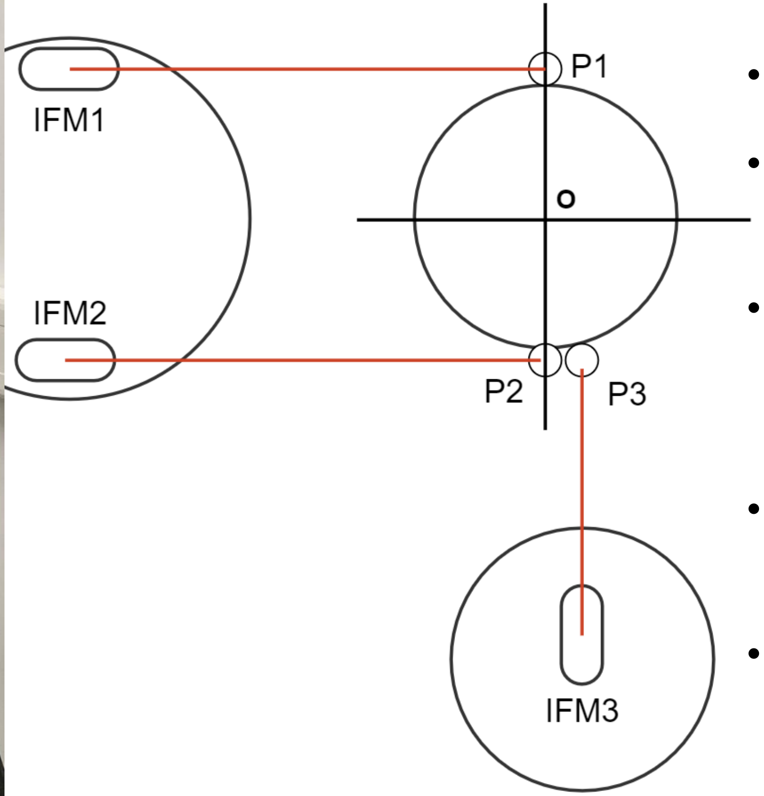
Pass 1 - camera in hand	
CoR Data Source	**Median of differences**
Laser tracker	4 µm
Photogrammetry	6 µm
LT and Photogrammetry	21 µm
Pass 2 - camera on frame	
CoR Data Source	**Median of differences**
Laser tracker	3 µm
Photogrammetry	47 µm
LT and Photogrammetry	26 µm

Description	**Max σ_{XYZ} AIP**	**Max σ_{XYZ} Magnet Fiducial**
Small AIP, frame cam	23 µm	10 µm
Large AIP, hand cam	41 µm	20 µm
Large AIP, frame cam	58 µm	16 µm

Instrument Pillar Design

HERA Pillar Measurements

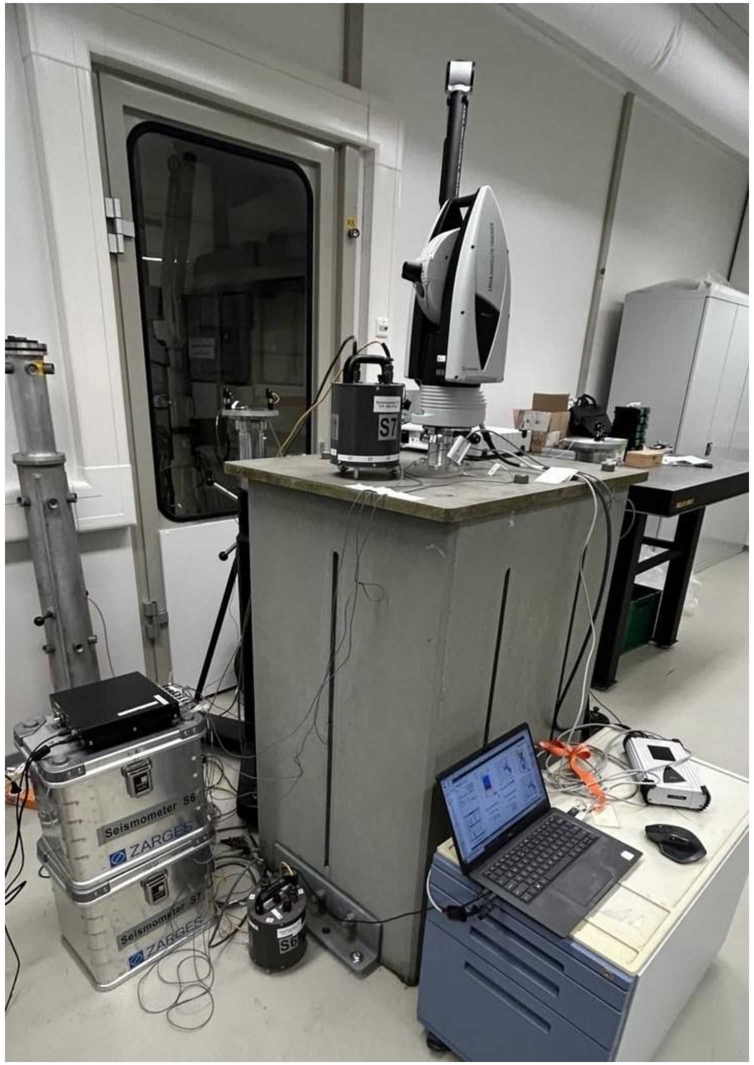




- Lightweight HERA pillar made for gently handled theodolites
- Now with weighty, rapidly moving LT.
- Pillar measured by set of 3 IFMs while excited by an LT automeasuring network
- Mathematical corrections were done to create planar perpendicular CS to easily represent the vibrations
- The pillar produced audible vibrations at (400 ± 25) Hz with the LT
- Measurements showed large elastic deformations of 10 µm (in X) respective 5 µm (in Y)
- **This pillar doesn't fulfil requirements for stable instrument stand**

Instrument Pillar Design

Concrete Block Measurements



- **1 ton concrete block pillar**

  opposite of the slender HERA pillar

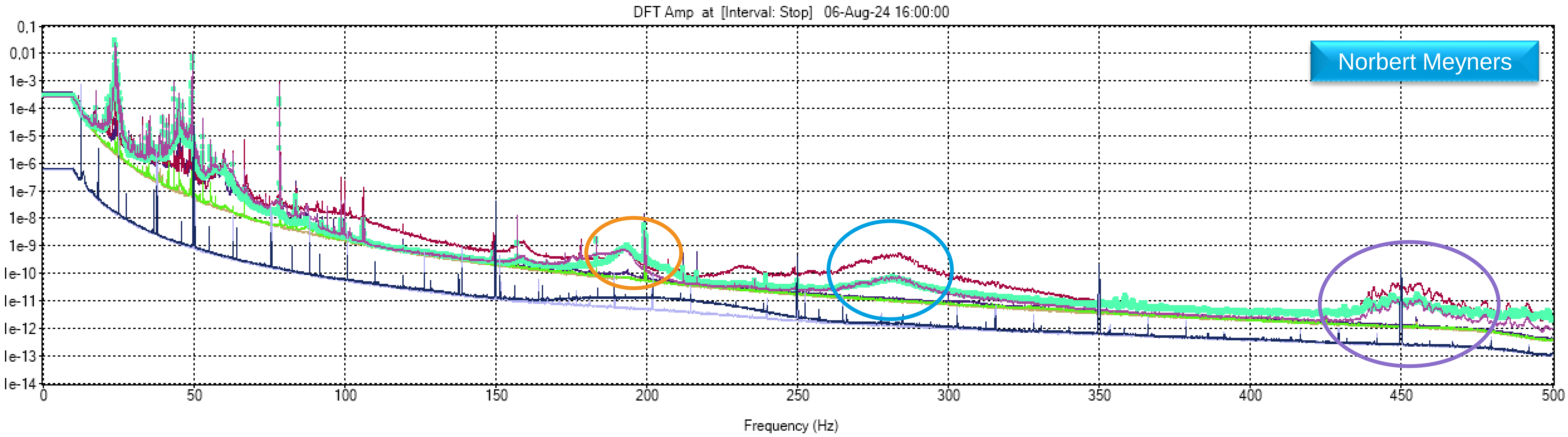
- Measured vibration spectrum with seismometers, accelerometers, and interferometers

- 4 hours duration
  ~same time as magnet referencing or girder alignment

Instrument Pillar Design

Concrete Block Results

- In the region of 0-100 Hz, there are typical DESY vibrations, only slightly amplified at the top of the pillar
- A sharp peak at ~200 Hz
- With slow peaks at 195 Hz, 270 Hz and 450 Hz where the ground is still, only the top of the pillar is excited



Instrument Pillar Design

Prototype design

- Requirements derived from previous tests were:
  - Deformations ≤ 1 μm
  - Lowest eigenfrequency above 100 Hz
  - Avoid laser tracker driving frequencies

Instrument Pillar Design

Prototype design

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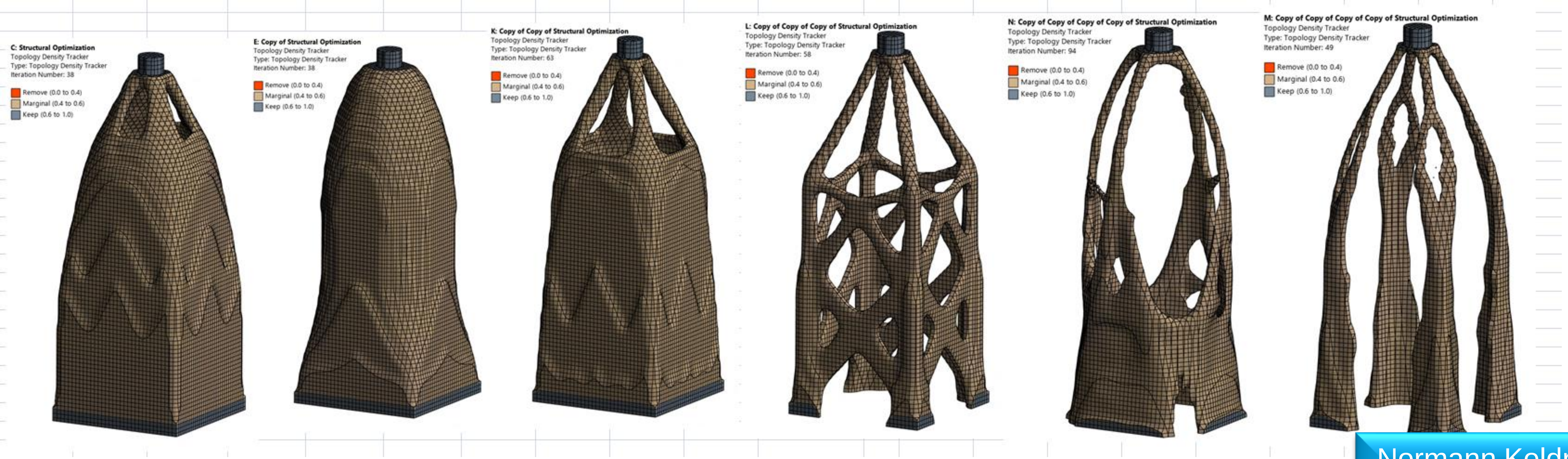
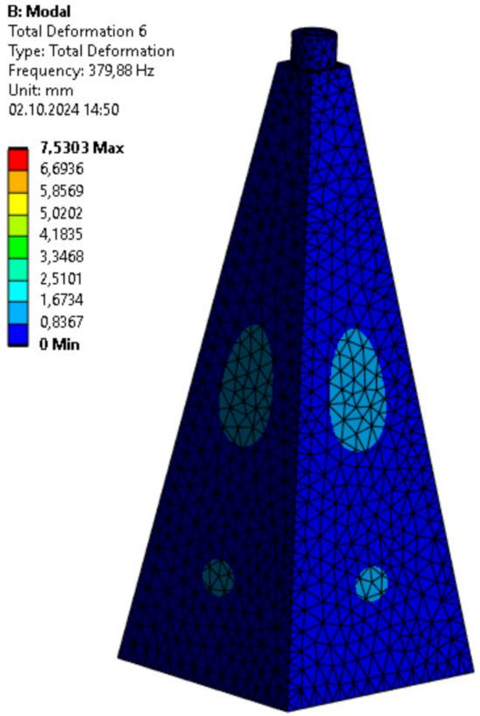
- Prototypes were created by FEM analysis to fulfil the criteria



Normann Koldrack

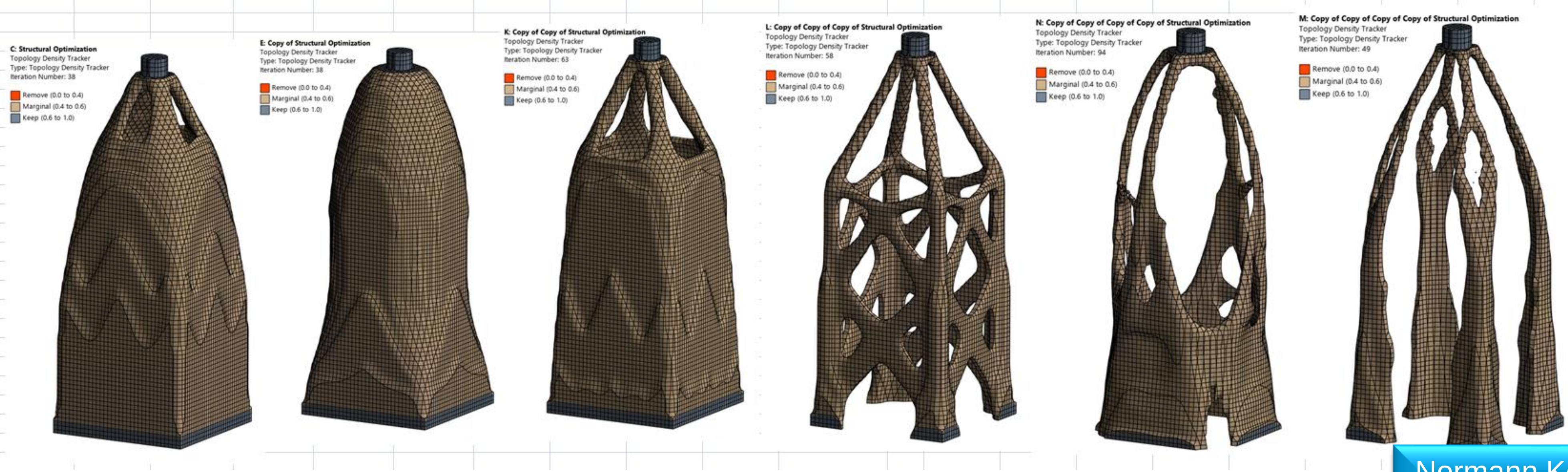
Instrument Pillar Design

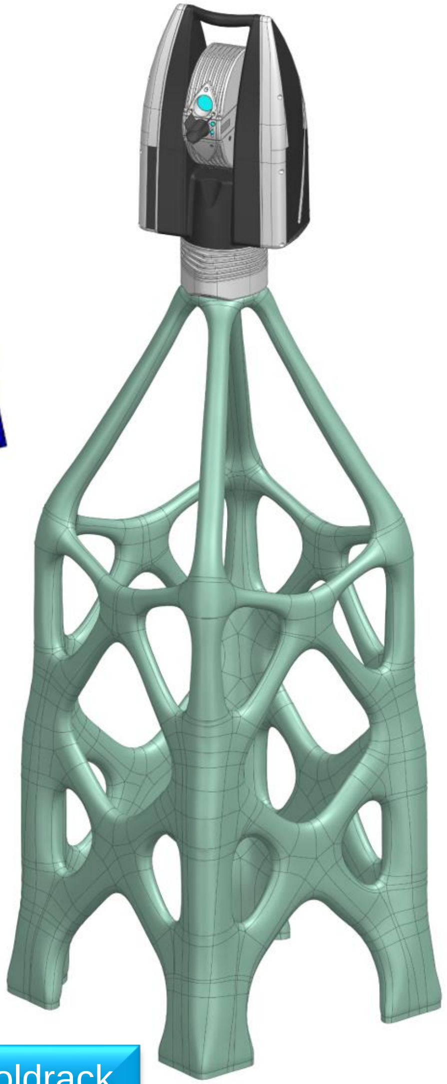
Prototype design



PETRA IV. NEW DIMENSIONS

- Requirements derived from previous tests were:
  - Deformations ≤ 1 µm
  - Lowest eigenfrequency above 100 Hz
  - Avoid laser tracker driving frequencies
- Prototypes were created by FEM analysis to fulfil the criteria
- Some prototypes will be manufactured and further tested





Normann Koldrack

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THANK YOU FOR YOUR ATTENTION

PETRA IV Alignment Overview

And thanks to my colleagues:
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DESY.

What to Remember – Ultimate Summary

Fiducialization – two methods

- LT - easier to automate
- Potential issues with PRD (LT) and geometry (PG)
- Further developed in parallel to mitigate risks

Instrument Pillar Design

- Laser Tracker has specific driving frequencies
- A variety of designed pillars will be manufactured and tested
- The designed pillars avoid the troubling frequencies

Software Tools Development

- Development of:
  - Measurements analysis tools
  - Automation tools
- Can be found at https://github.com/Jadracka/

Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

Jana Barker
Petra IV Project Geodetic Engineer
MEA2 – Applied Geodesy Department
jana.barker@desy.de, piv-alignment@desy.de
+49 40 8998 2325