CLIC Module Status Update and the Results of Recent Studies

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With thanks to With thanks to: Mateusz Sosin, Joshua Brown, Hélène Durand, Andrea Latina, Michael Guinchard

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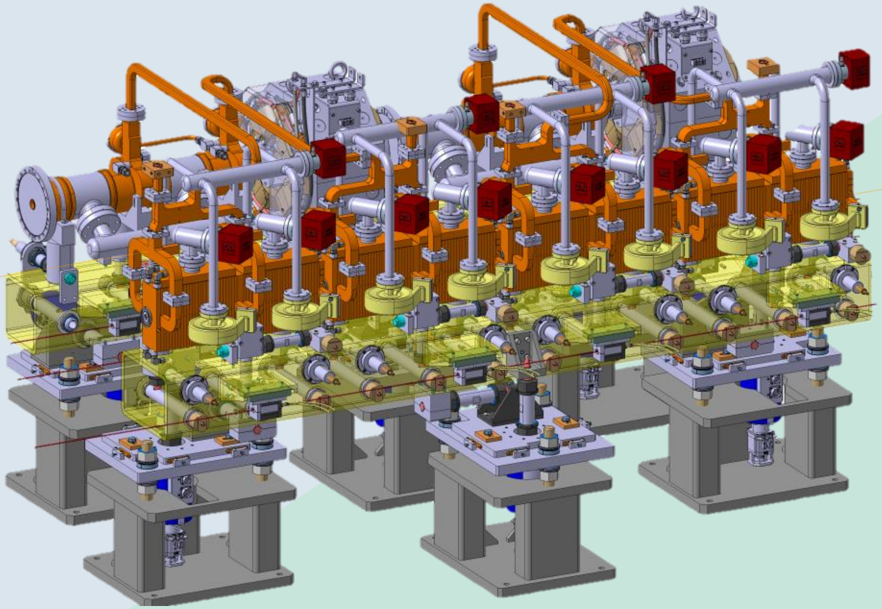
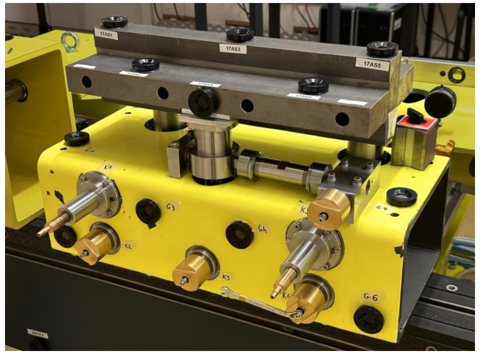
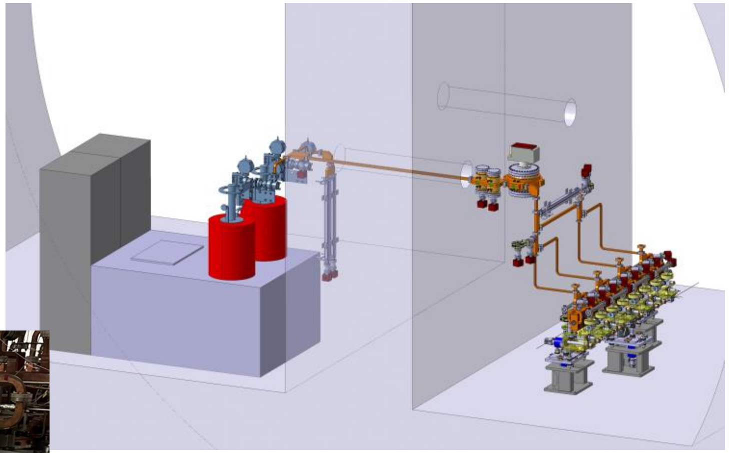


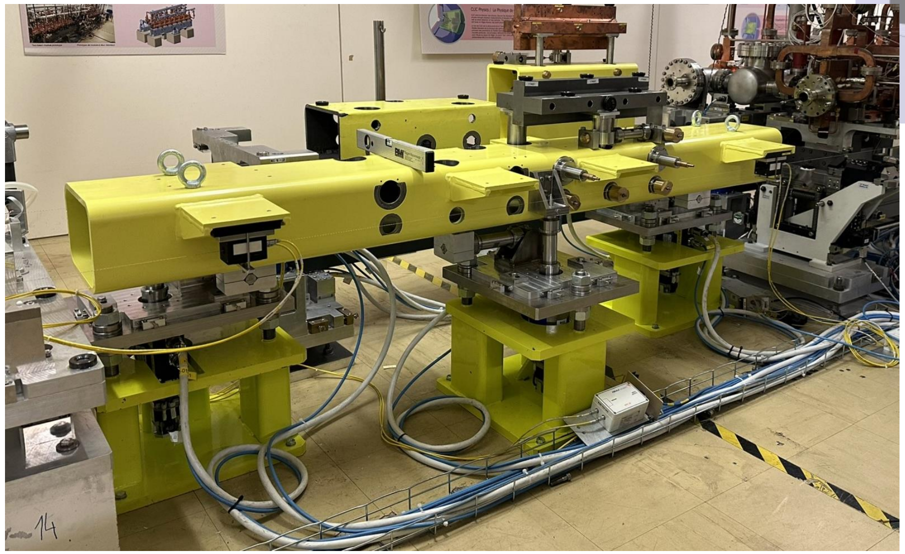
CLIC Mini Workshop
December 12th 2023

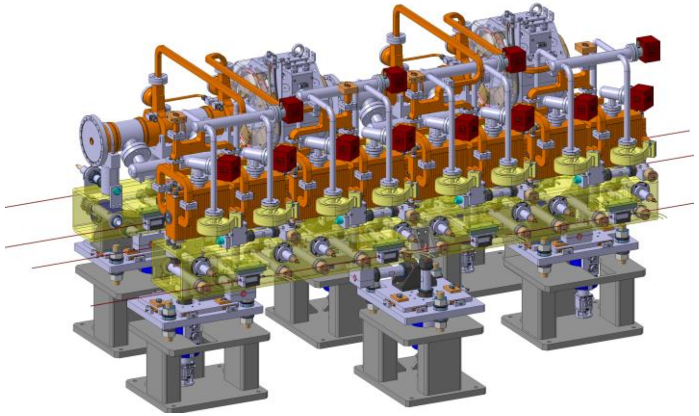
Progress Since Last Meeting

- Testing of the structure prealignment prototype (V4)
- Assembly and testing of the module positioning and active alignment systems.
- Further design and optimisation for the TBM and Klystron modules
- More…







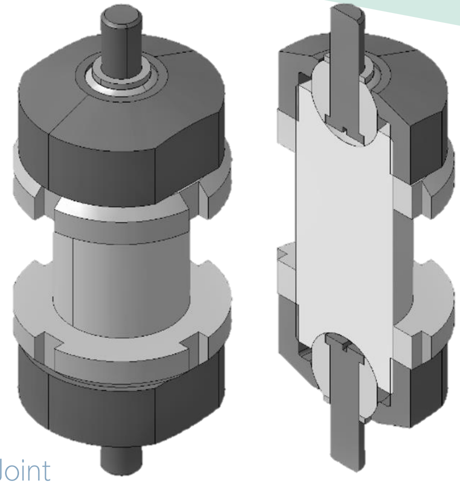


Structure Prealignment

6 Axis precision adjustment system:

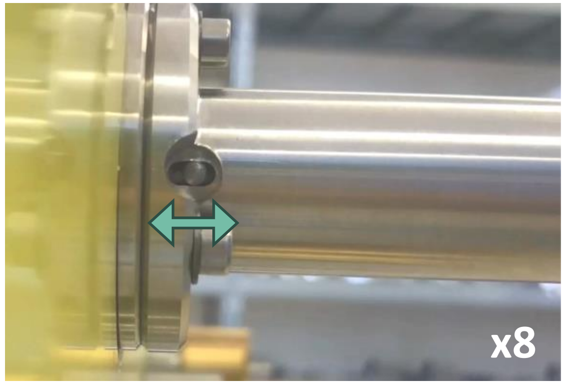
- Now uses ‘universal joints’: axially stiff but allow movement in all other axes.
- 3 vertical joints (red), 2 lateral joints (blue), and a longitudinal joint (green)
- Uses two adjustment mechanisms for sub-micron adjustment over ±1.5mm.
  - Wedge mechanism = 30μm/turn
  - Differential thread = 40μm/turn
- Support accommodates thermal expansion of the structure.

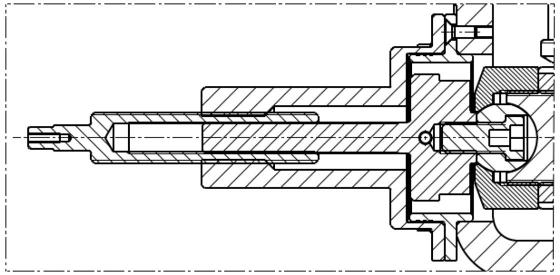
Required for structure 14μm & 140μrad prealignment



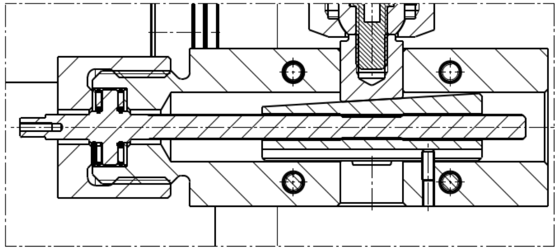
Right:
Universal Joint

Below: Differential thread adjustment

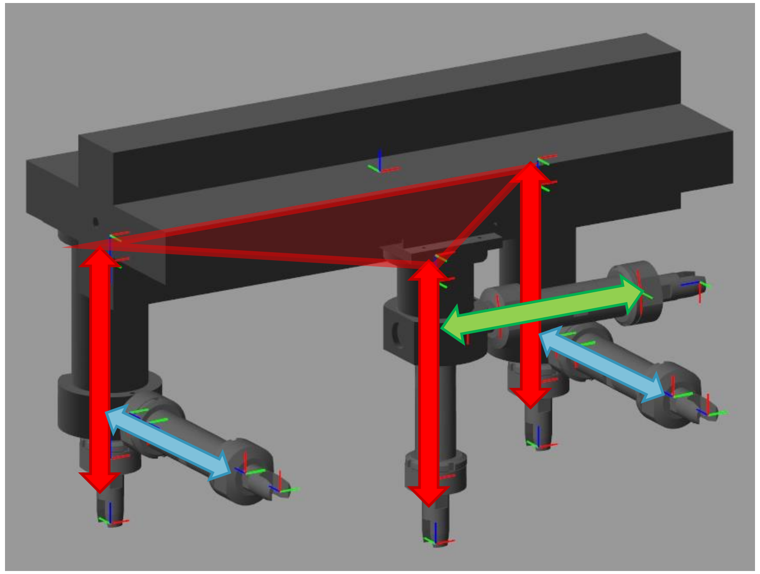




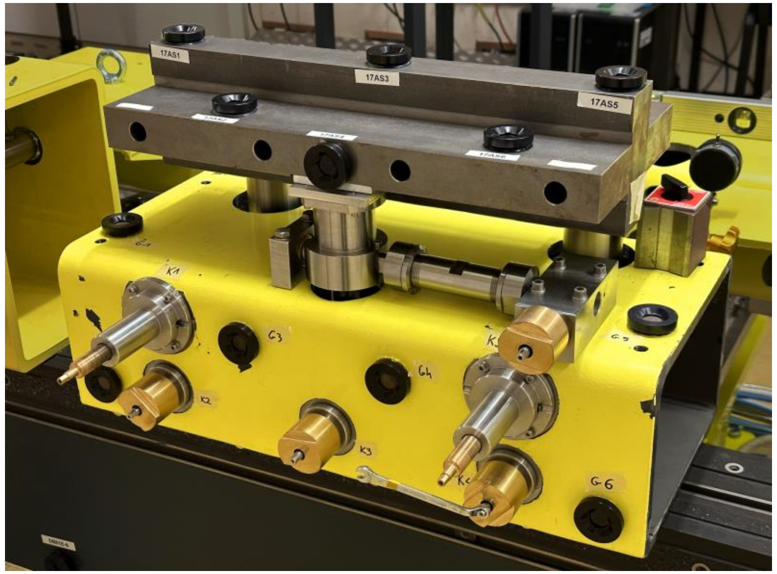
Differential Threads



Wedge Mechanism



Simulink Prealignment Platform Model



Prealignment Platform Prototype

Structure Prealignment Testing

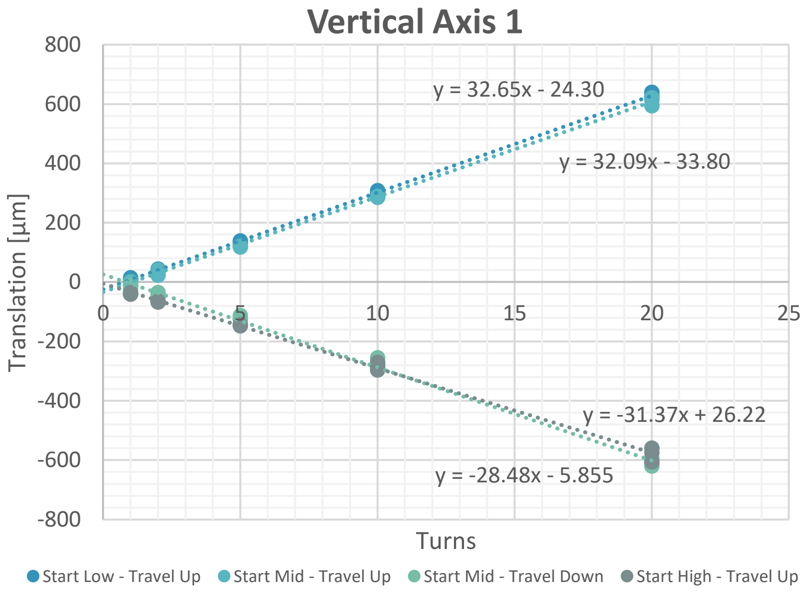
Testing procedure:

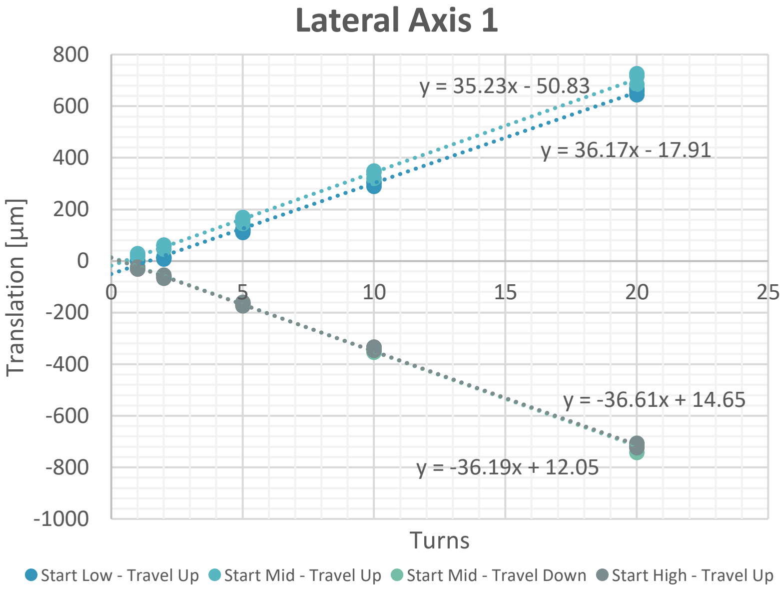
- Each axis was adjusted and the displacement per revolution was measured using a laser tracker

Testing results:

- Sub-micron resolution in all axes
- Average range 2.85mm
  - Sufficient to accommodate tolerances on the girder/structures
- Adjustment rate close to design
- Backlash <30µm
  - Current design does not attempt to eliminate backlash, but it can be avoided through correct operation

Met all requirements



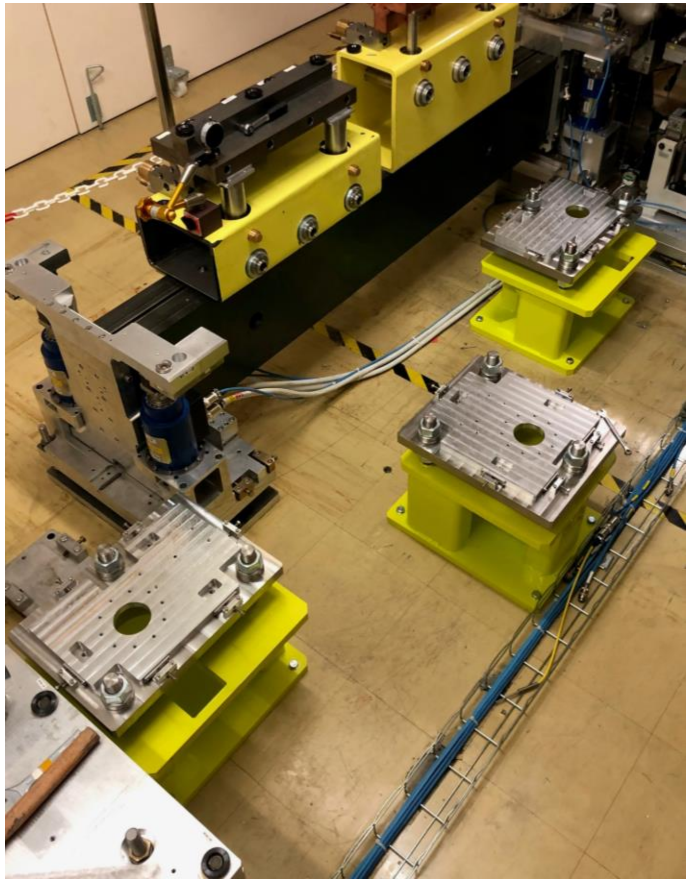


Axis	Axis Type	Measured Rate [µm]	Design Rate [µm]	Backlash [µm]	Backlash [turns]
Vertical 1	Wedge	31.147	30	22.544	0.724
Vertical 2	Wedge	31.162	30	19.830	0.636
Vertical 3	Wedge	29.370	30	8.099	0.276
Lateral 1	Differential Thread	36.052	40	23.863	0.662
Lateral 2	Differential Thread	35.591	40	27.722	0.779
Longitudinal	Wedge	32.409	30	17.578	0.542

Module Prototype Assembly

Bases

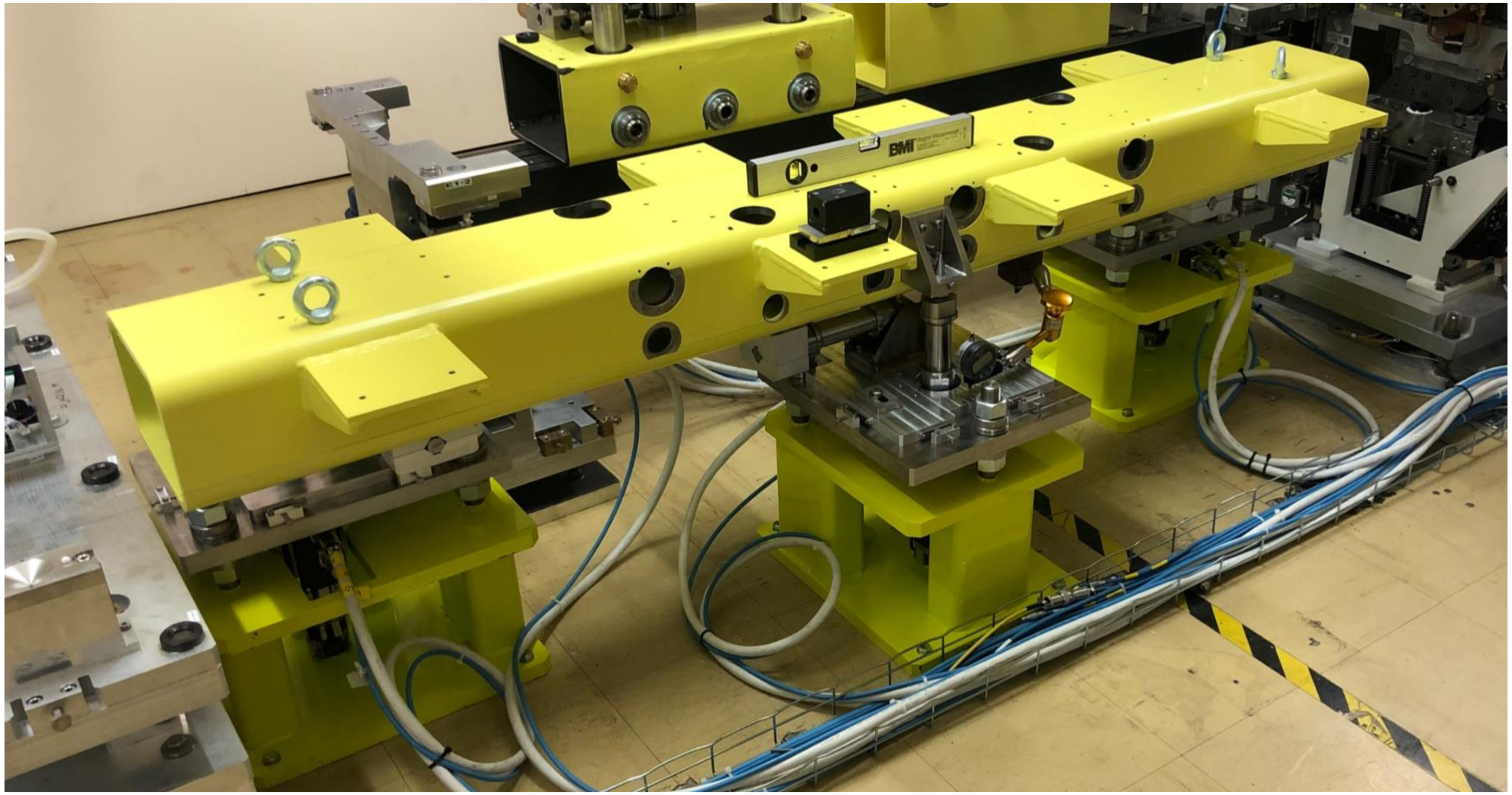
Base plates installed



Actuators mounted

Module Prototype Assembly

Girder installed upon the actuators and supports



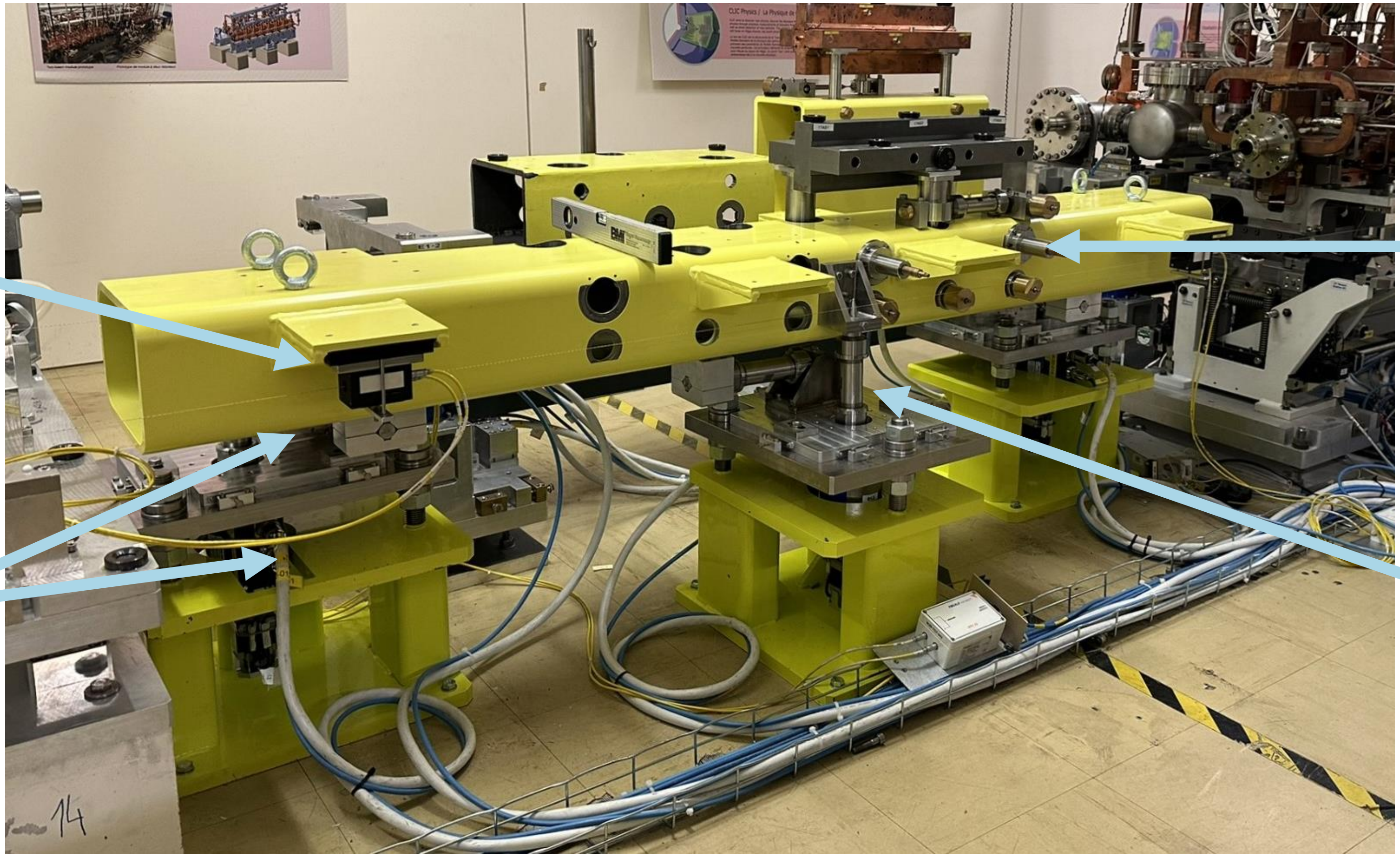
Current Module Support Prototype

Current Module Support Prototype

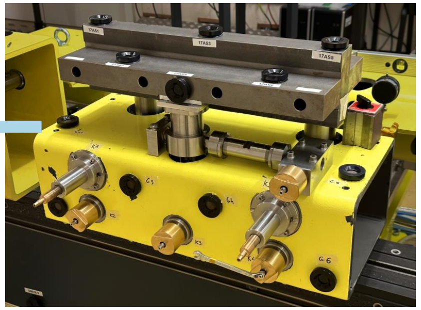
The current CLIC module support prototype in Bld169

Capacitive WPS on girder,
Kevlar/Carbon wire

Linear actuator, 0.26µm/step,
6mm range, 162N/µm
stiffness



SAS prealignment platform
integrated into girder

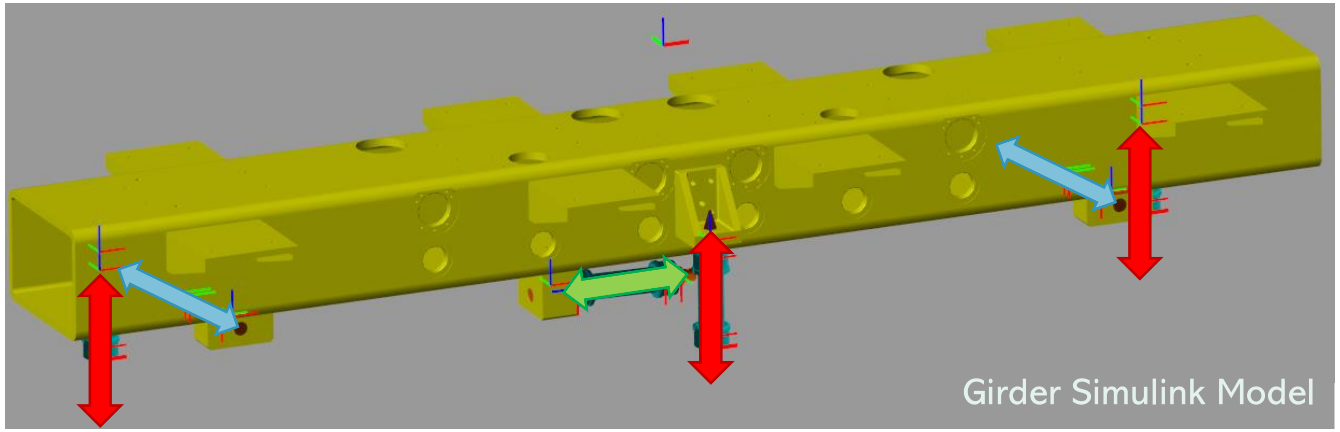


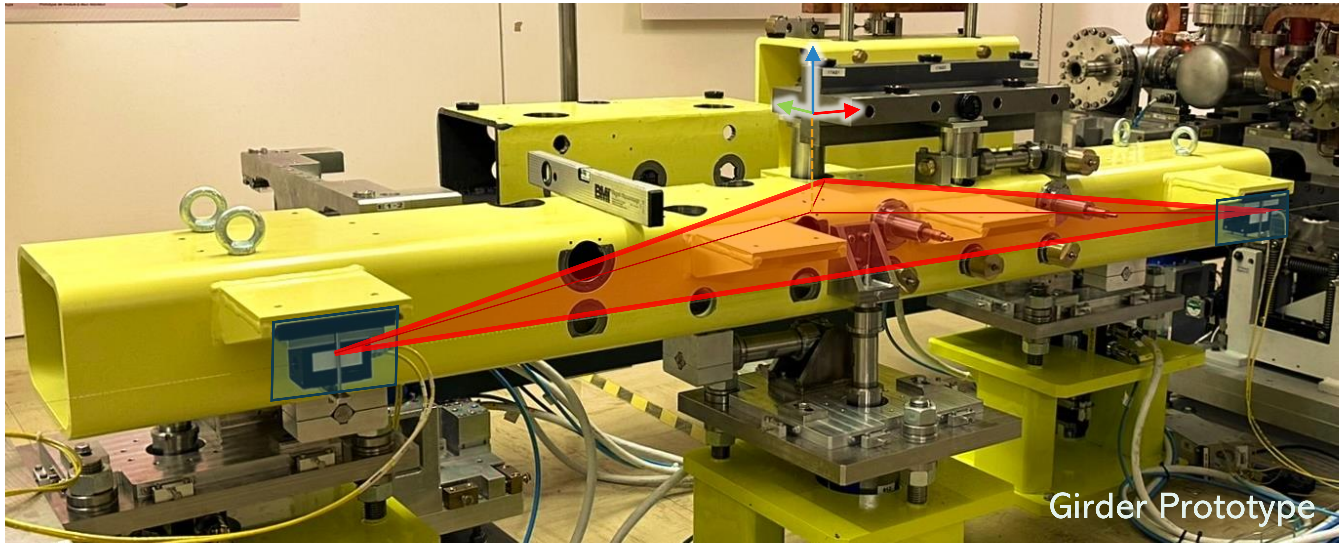
Girder Support Joint

Active Alignment

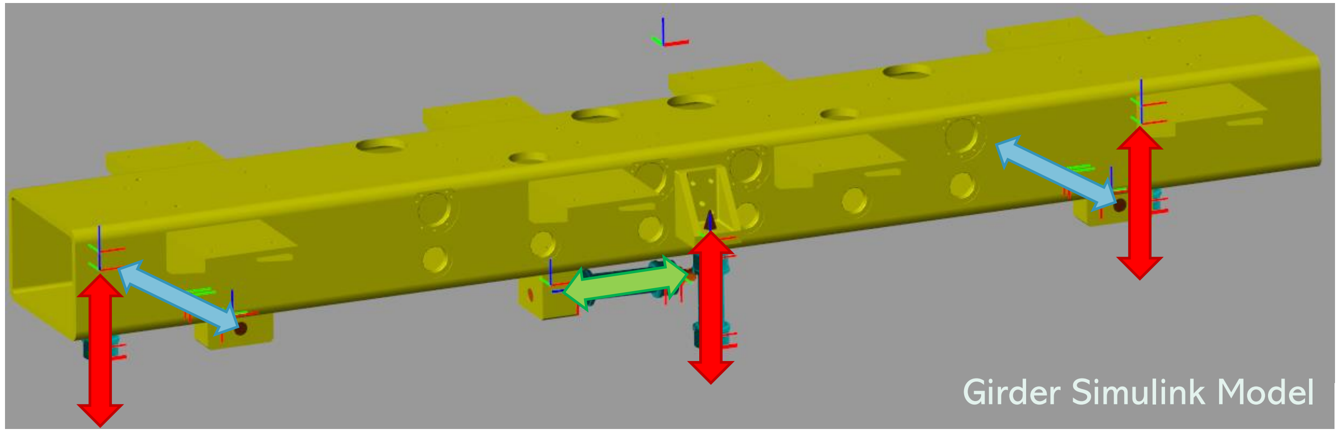
Kinematically similar to the SAS support platform:

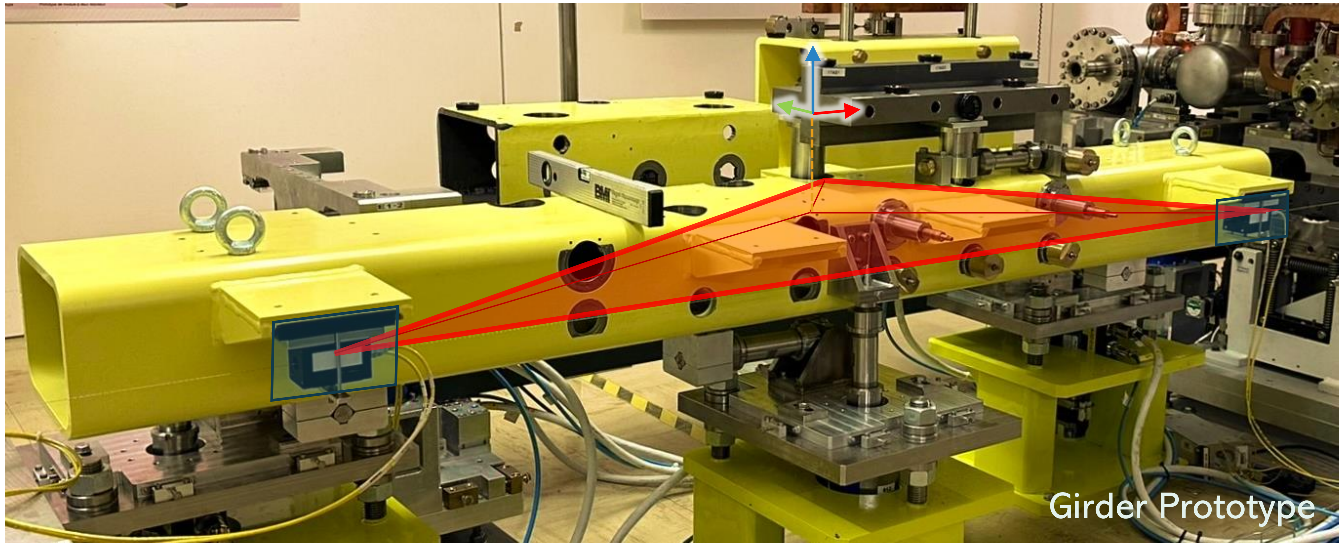
- Girder supported by 6 high stiffness universal joints
  - The joints are larger to accommodate the increased mass
- 5 Joints are actuated to provide the active alignment
  - 3 vertical actuators (red)
  - 2 lateral actuators (blue)
  - The longitudinal joint is fixed
- Three Wire Position Sensors provide the positional feedback
  - 2 on one side, 1 on the other
  - Provide point coordinates, which can be used to determine a plane, from which the girder coordinate system can be found
- Comparable to the kinematically ideal model created in Simulink (top right)





Active Alignment



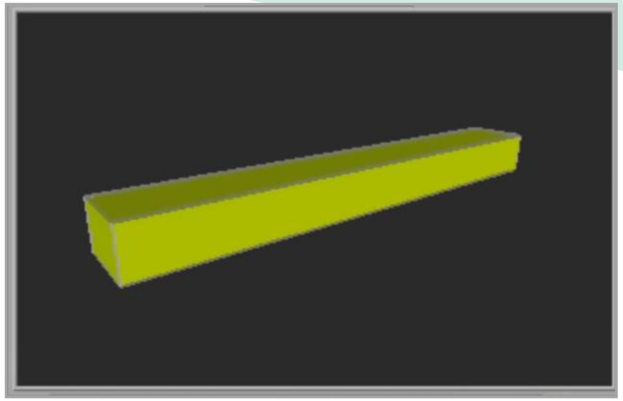


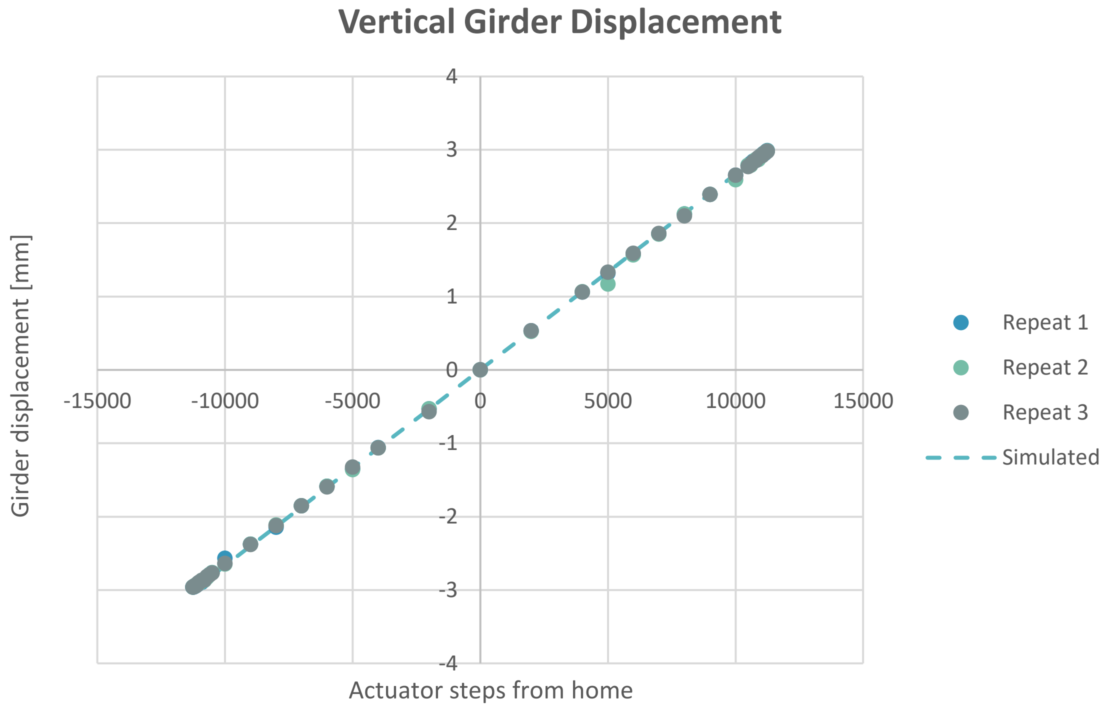
Active Alignment Testing

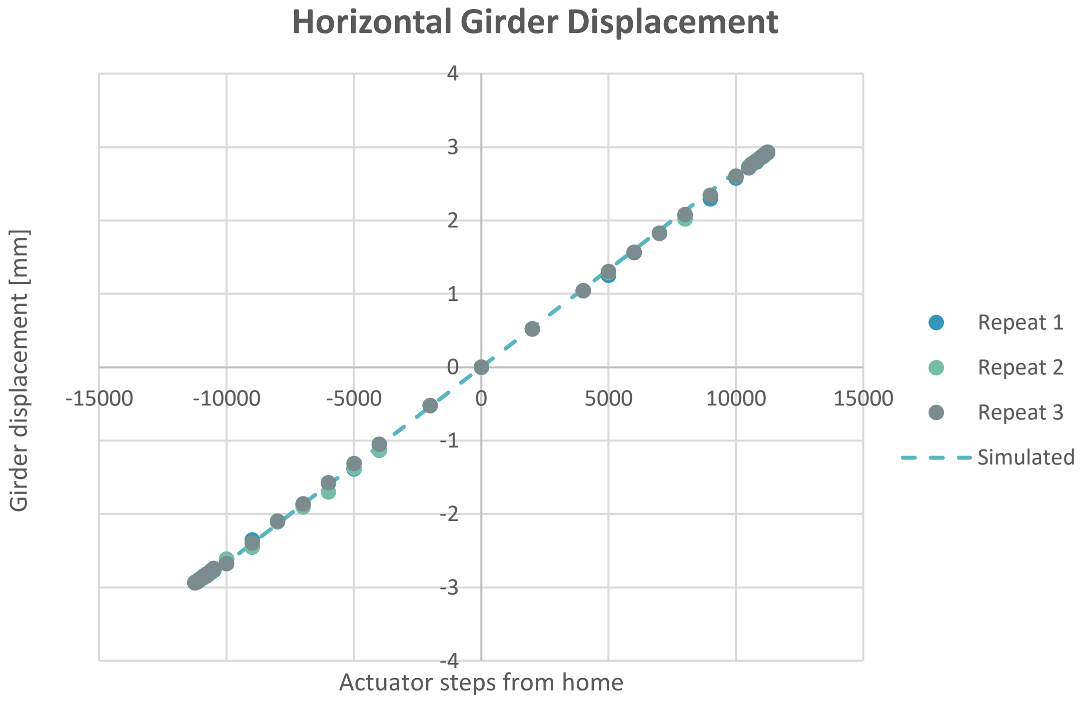
Initial ‘dead reckoning’ tests:

- Translation over the full length of travel
- Position measured from WPS
- Compared to the Simulink model
- Expected sources of error (parasitic motion)*

The translation of the girder as displayed on the LabView control panel GUI







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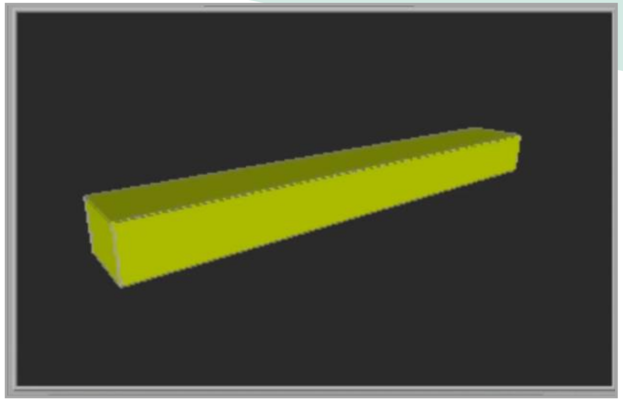
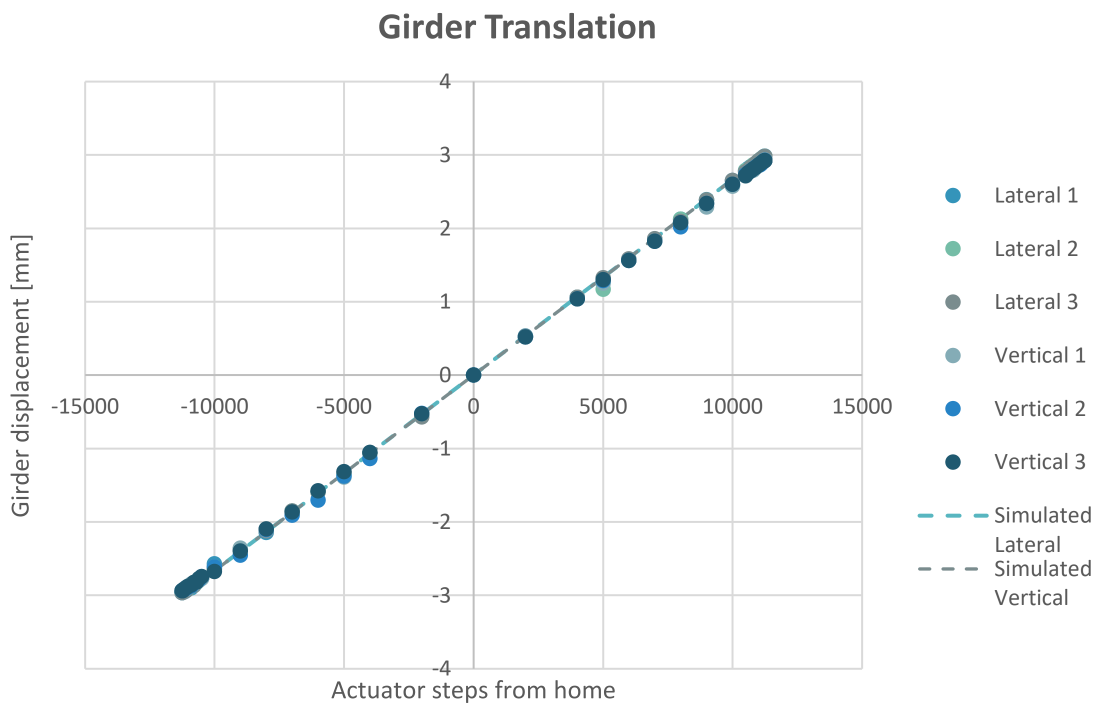


The translation of the girder as displayed on the LabView control panel GUI



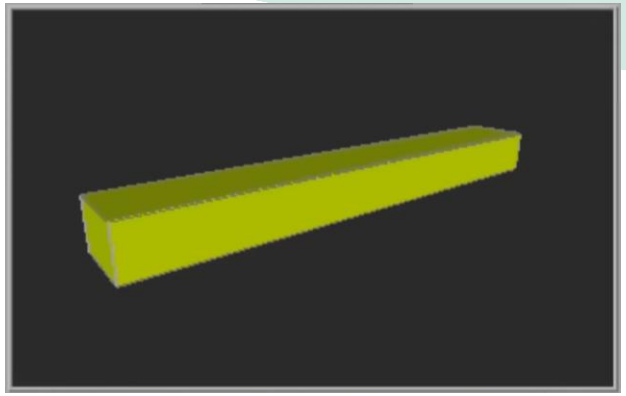
	Parameter	Design	Average Measured	Max Deviation
Vertical	Rate [µm/step]	0.2667	0.2641	-0.0025
	Range [mm]	5.999*	5.943	-0.0569
	Position error at EOT [µm]	-	99.5	164.6
	Position error at 1mm [µm]	-	18.6	37.0
Lateral	Rate [µm/step]	0.2666	0.2607	-0.0060
	Range [mm]	5.999*	5.865	-0.1344
	Position error at EOT [µm]	-	101.8	114.5
	Position error at 1mm [µm]	-	41.4	69.7

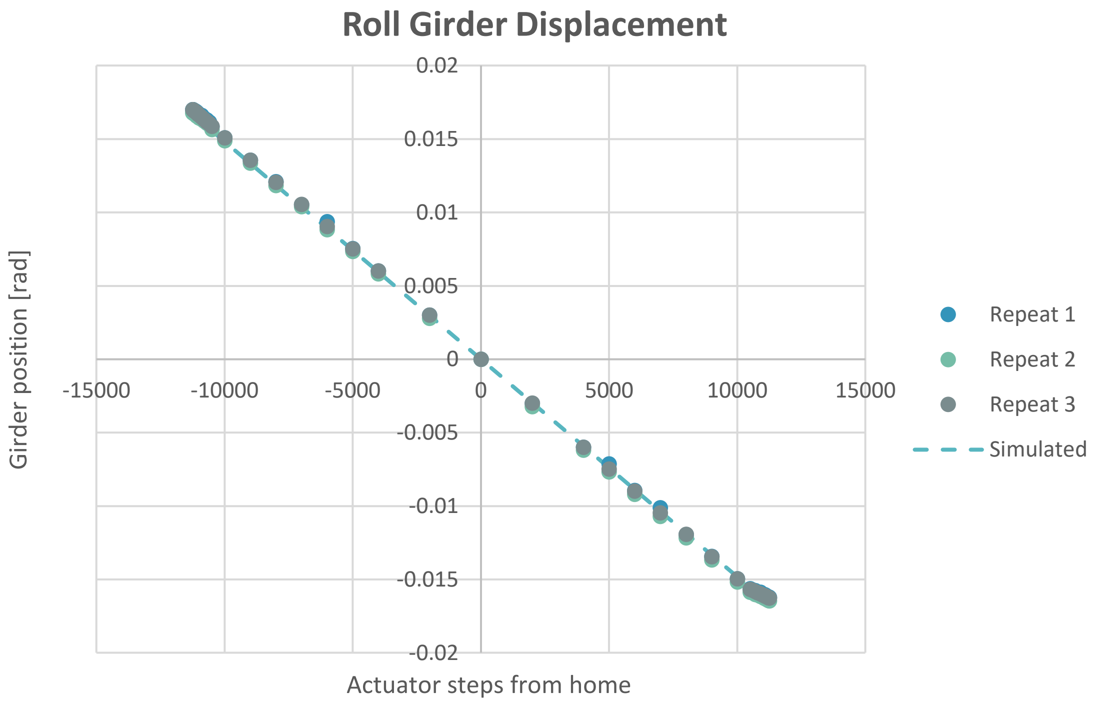
Active Alignment Testing

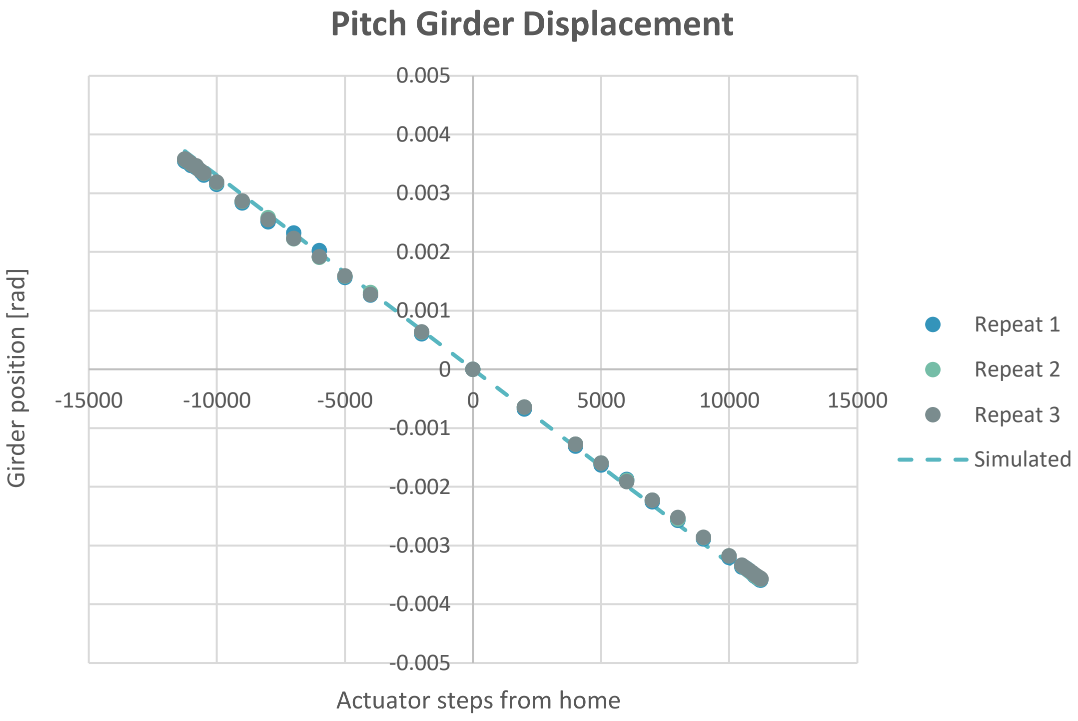
Initial 'dead reckoning' tests:

- Rotation over the full length of travel
  - E.g.: -3mm to 3mm V1 & V3, 3mm to -3mm V2
- Position measured from WPS
- Compared to the Simulink model
- Expected sources of error (parasitic motion)*

The rotation of the girder as displayed on the LabView control panel GUI







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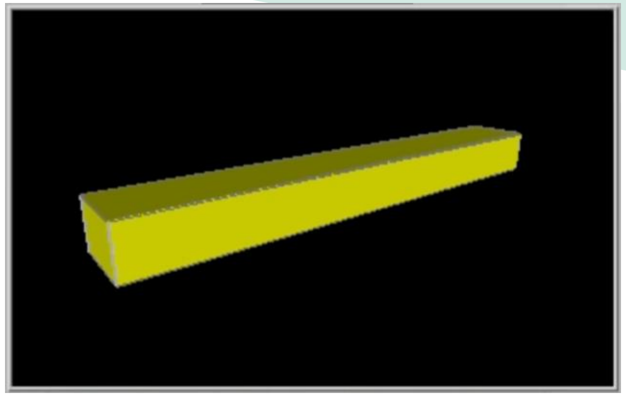

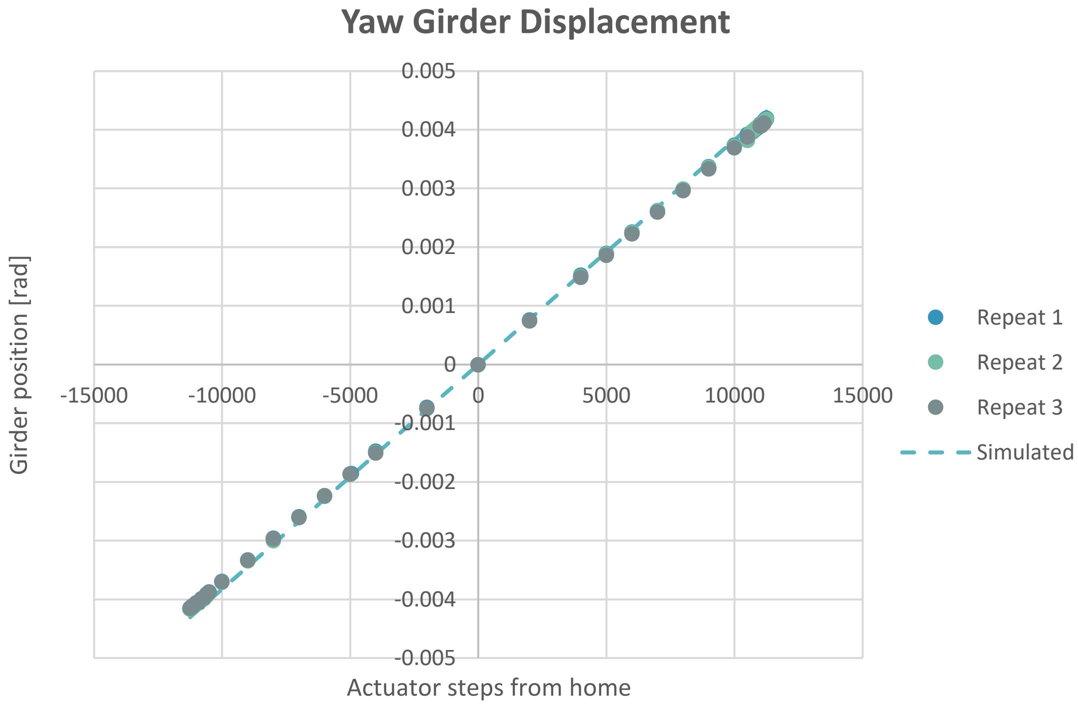

	Parameter	Design	Average Measured	Max Deviation
Roll	Rate [mrad/step]	1.482	1.478	-0.0041
	Range [mrad]	33.335	33.243	-0.1344
	Position error at EOT [μrad]	-	410.4	481.2
	Position error at 1mm [μrad]	-	145.7	269.9
Pitch	Rate [mrad/step]	0.3304	0.3178	-0.0126
	Range [mrad]	7.433	7.149	-0.2843
	Position error at EOT [μrad]	-	155.8	168.3
	Position error at 1mm [μrad]	-	49.8	56.2
Yaw	Rate [mrad/step]	0.3826	0.3702	-0.0124
	Range [mrad]	8.595	8.315	-0.2792
	Position error at EOT [μrad]	-	171.7	200.5
	Position error at 1mm [μrad]	-	43.6	53.3

Active Alignment Testing

Initial 'dead reckoning' tests:

- Rotation over the full length of travel
    - E.g.: -3mm to 3mm V1 & V3, 3mm to -3mm V2
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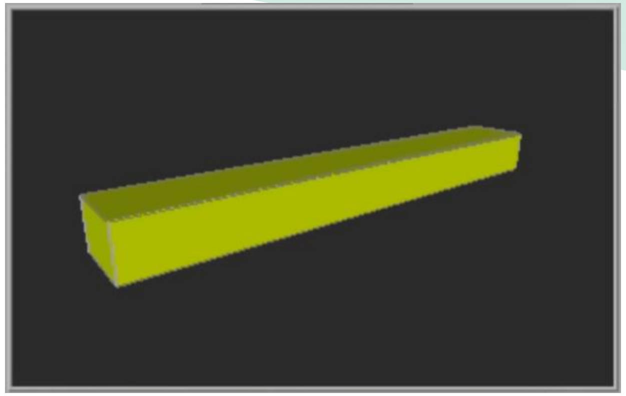

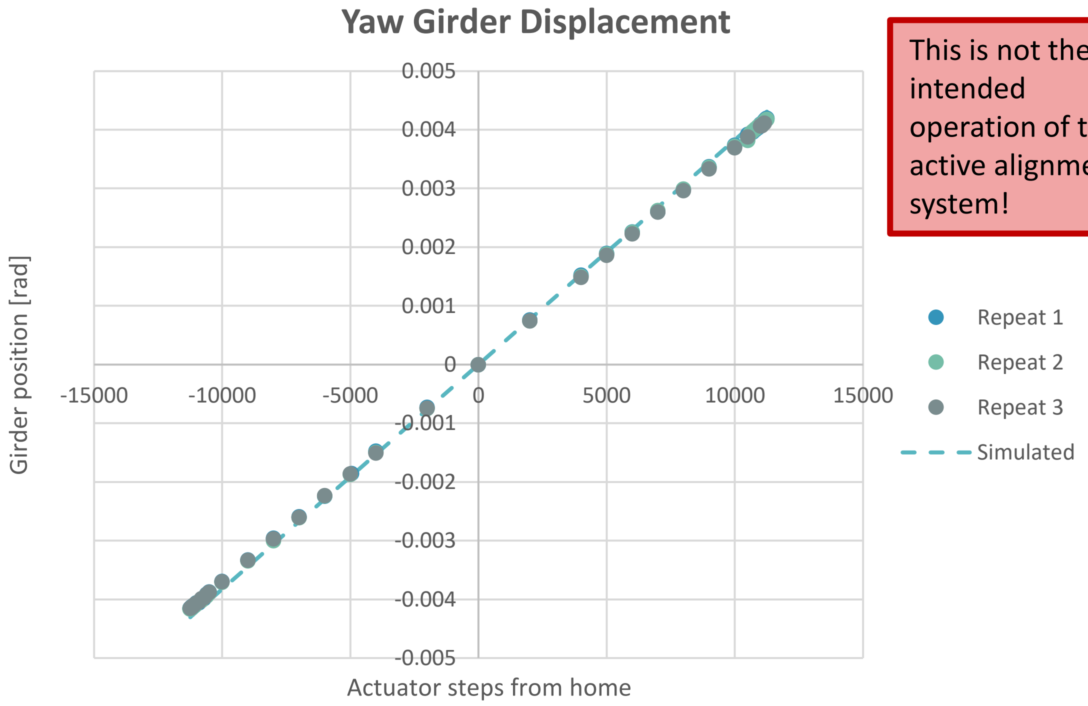

This is not the intended operation of the active alignment system!

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Active Alignment Testing

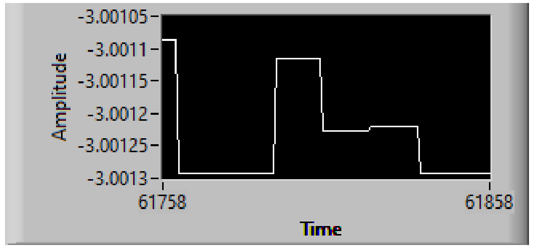
The active alignment system will always rely upon feedback from the WPS.

These charts show manual readjustment to an arbitrary position using the feedback.

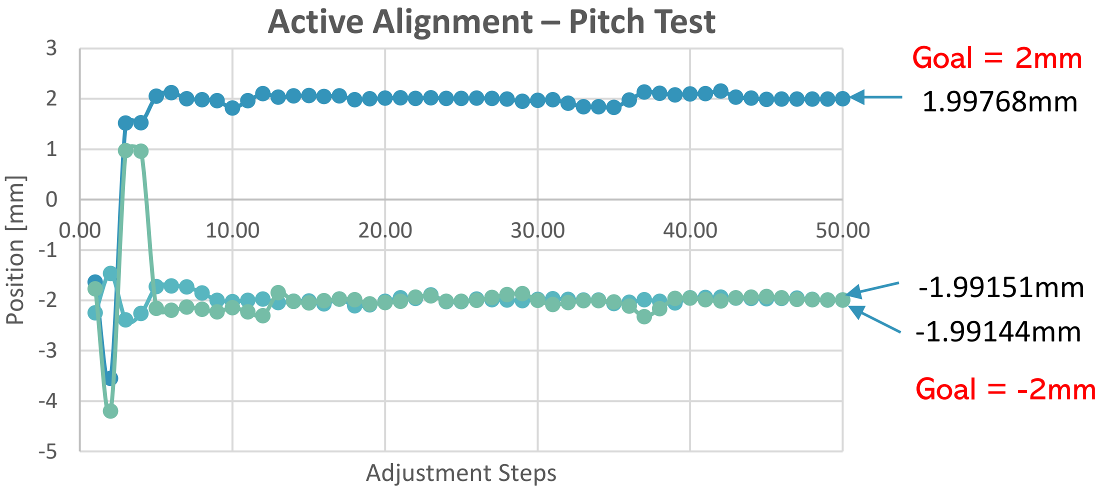
- Top: pitching to ±2mm
- Bottom: yawing to ±3mm

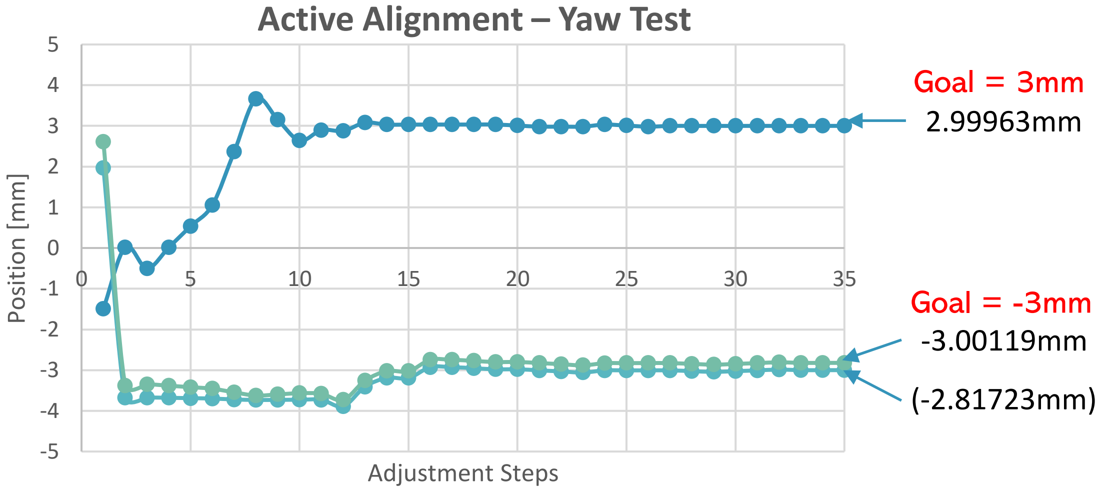
Possible to position down to <9μm manually

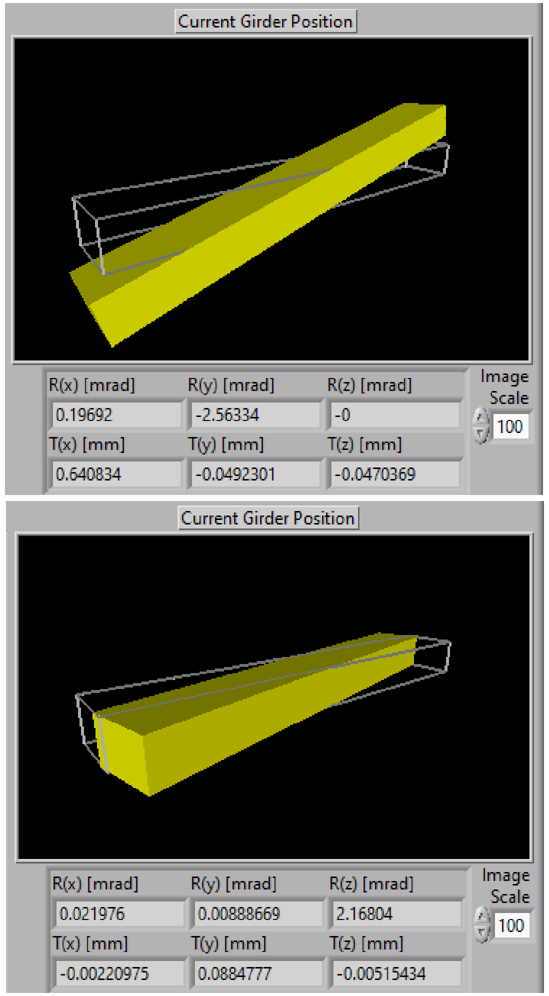
Demonstrates that the automatic alignment process is technically possible



WPS Stability <1μm





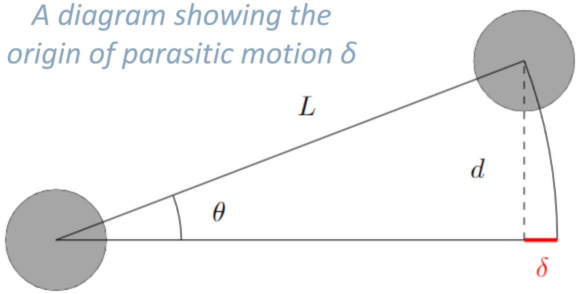


Girder Position GUI

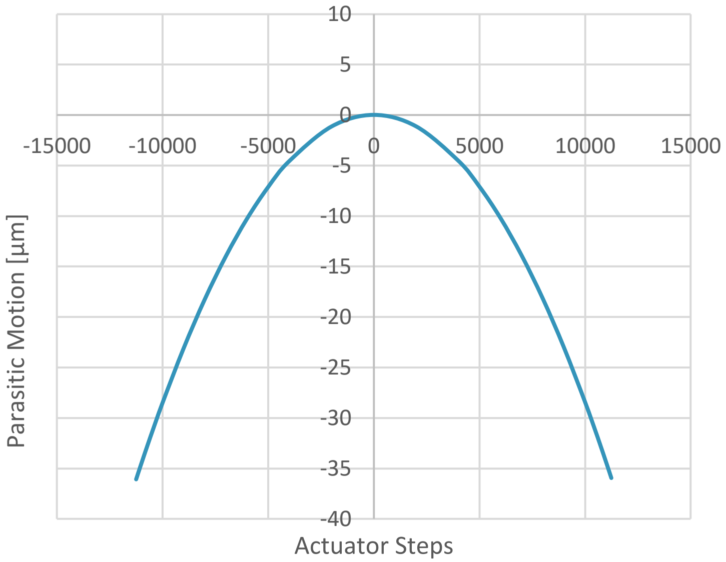
Parasitic Motion

- A source of mechanical error: when the module is moved in one axis, it will experience a small displacement in the perpendicular axes.
- This a known and expected consequence of kinematics of the system.

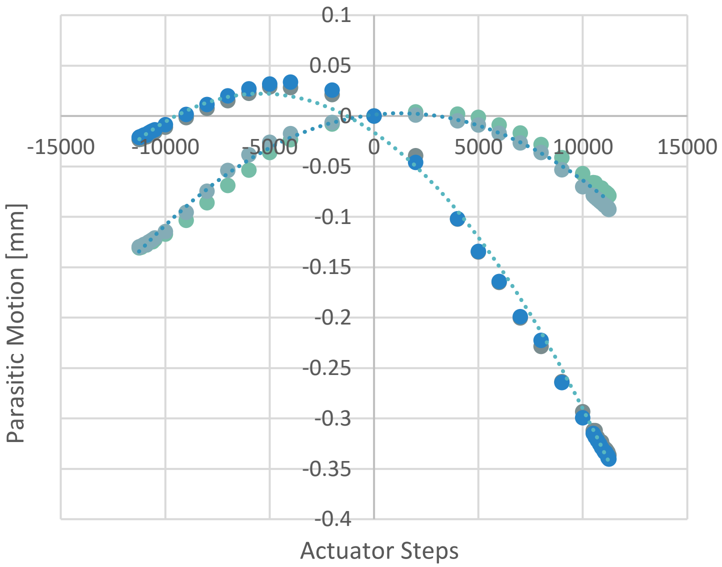
A diagram showing the origin of parasitic motion δ



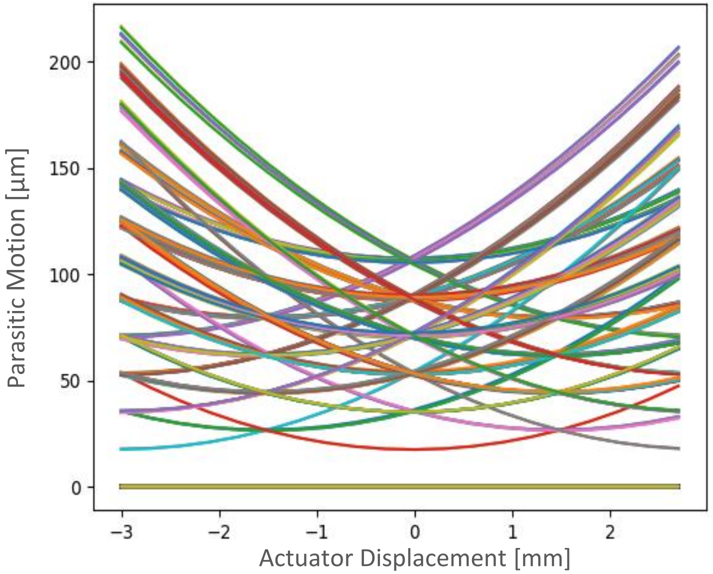
- Misalignments of the base plates will angle the joints in the neutral position.
- This will increase the impact of the parasitic motion at the extremes of travel.



The theoretical horizontal parasitic motion due to vertical translation

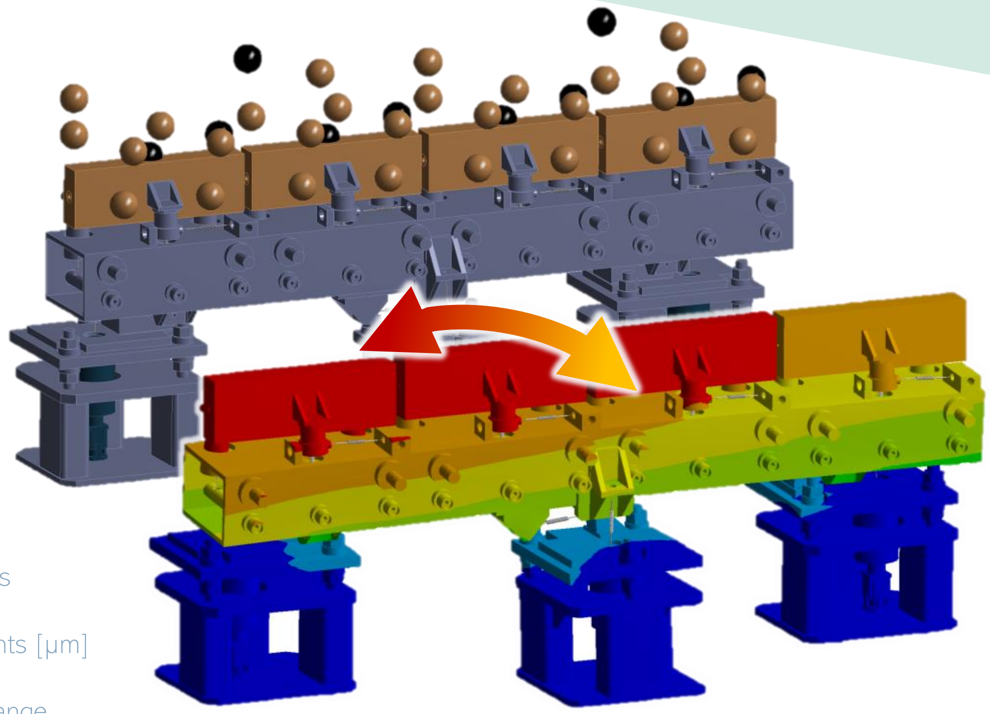


The measured horizontal parasitic motion due to vertical translation



A study into the impact of baseplate misalignment on the magnitude of parasitic motion

Stability Constraints



Structure Jitter Requirements (CDR)

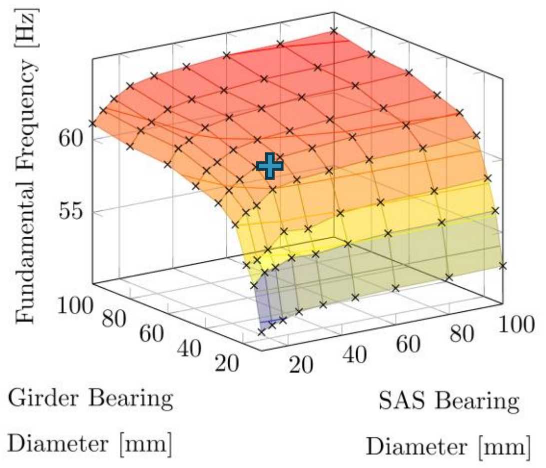
- RMS jitter tolerance which leads to a 1% luminosity loss
  - Accelerating structure vertical position = 1.4µm

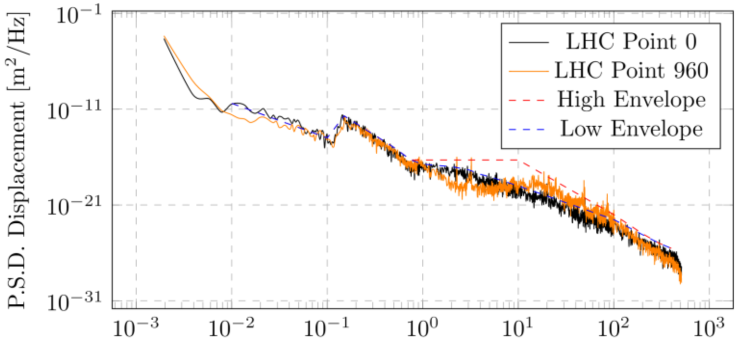
Structure Stability Analysis

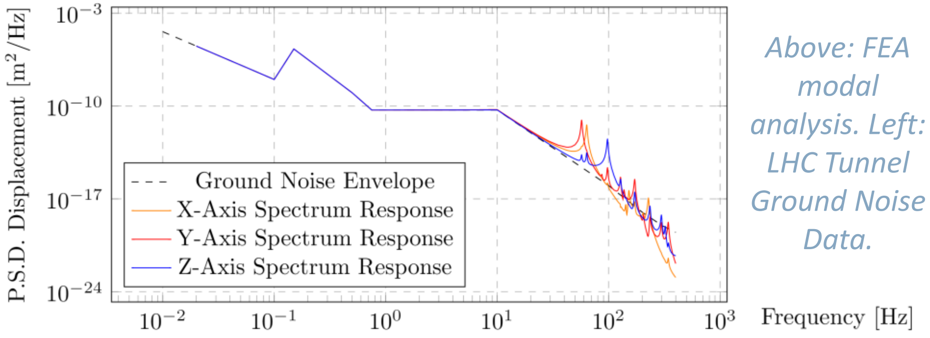
- Module is a 'hard mount' support
- Joint stiffness is dependent on bearing diameter
  - Bearings were selected to force the fundamental frequency over 60Hz
- Ground noise data from the LHC tunnel was used to predict the p.s.d. displacements
  - Less than 0.05µm >0.1Hz

Axis	Frequency Range 0.08Hz+	0.1Hz+	1Hz+
X	0.445	0.014	0.003
Y	1.375	0.028	0.003
Z	0.905	0.042	0.001

Left: the rms structure displacements [µm] for a given frequency range







Above: FEA modal analysis. Left: LHC Tunnel Ground Noise Data.

Stability Testing

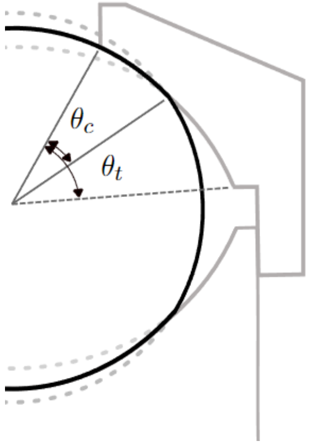
Experimental modal analysis:

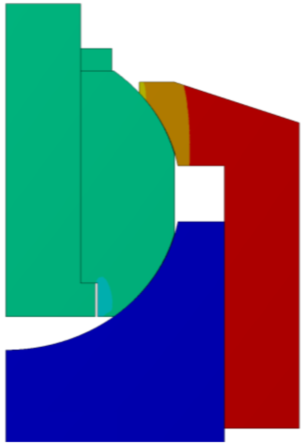
- Surface mounted accelerometers
- Non-contact laser vibrometers

- **To be performed early next year…**

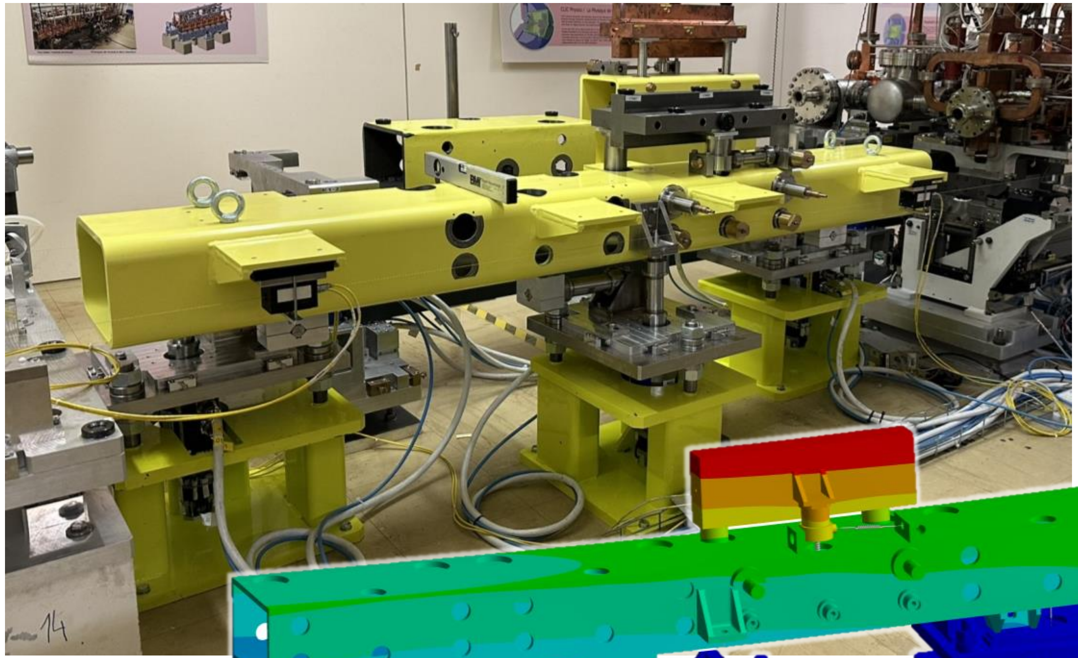
Supplementary analysis has been carried out

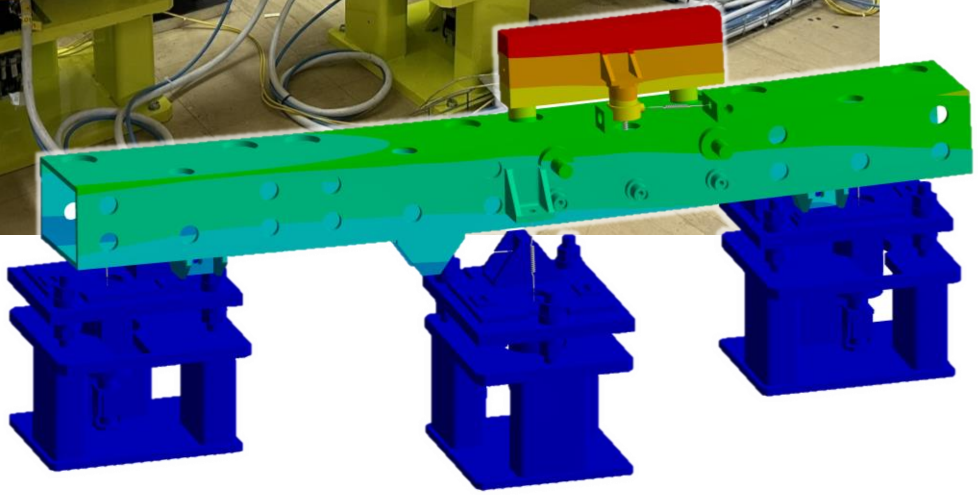
- Modal analysis representative of the true prototype assembly
- Investigation of the wear on used spherical bearings
  - Contact area ratio measured to be between 0.42 and 0.47
  - Close to the 0.5 originally assumed in the analysis





The contact area measured from the wear on the bearings



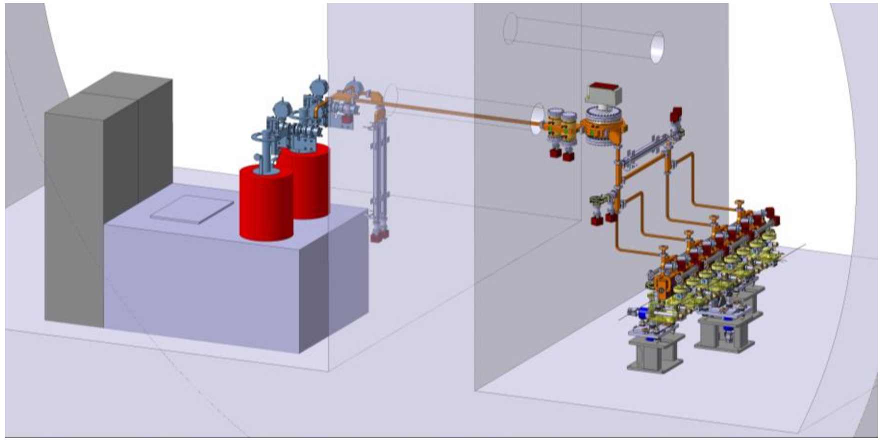


Above: Current module assembly. Right: The repeated analysis representative of the current prototype

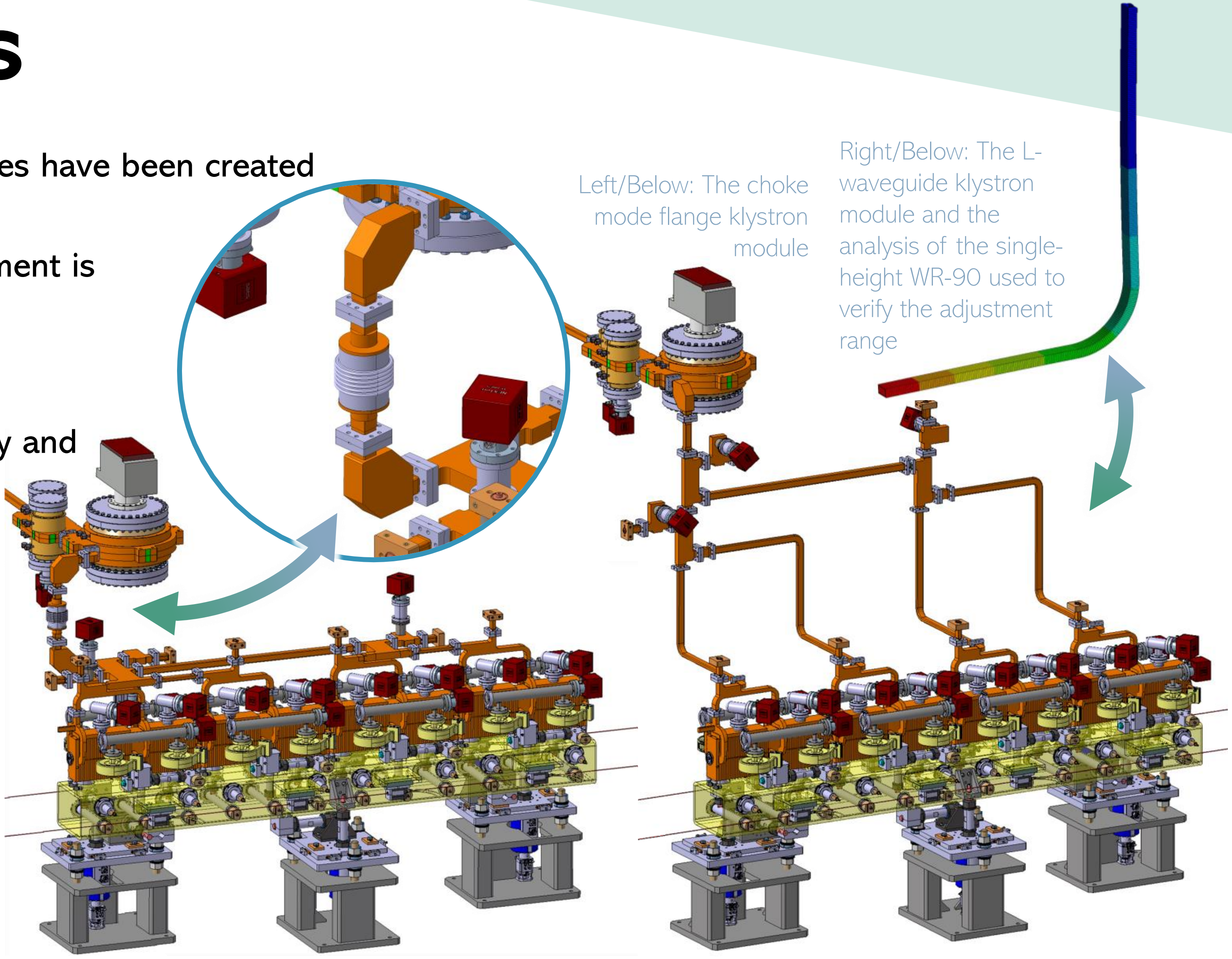
Expected frequency >80Hz

Klystron Modules

- Two variations of Klystron powered modules have been created
    - Based on the RF geometry provided by Ping Wang
- The required flexibility for the active alignment is provided by:
    - A choke mode flange (right)
    - (Relatively) flexible single-height waveguide
- Both provide 0.36mm adjustment vertically and 0.81mm of adjustment horizontally
    - Sufficient for the 'emittance bumps' ~100μm



L-shaped waveguide Klystron module tunnel spacing

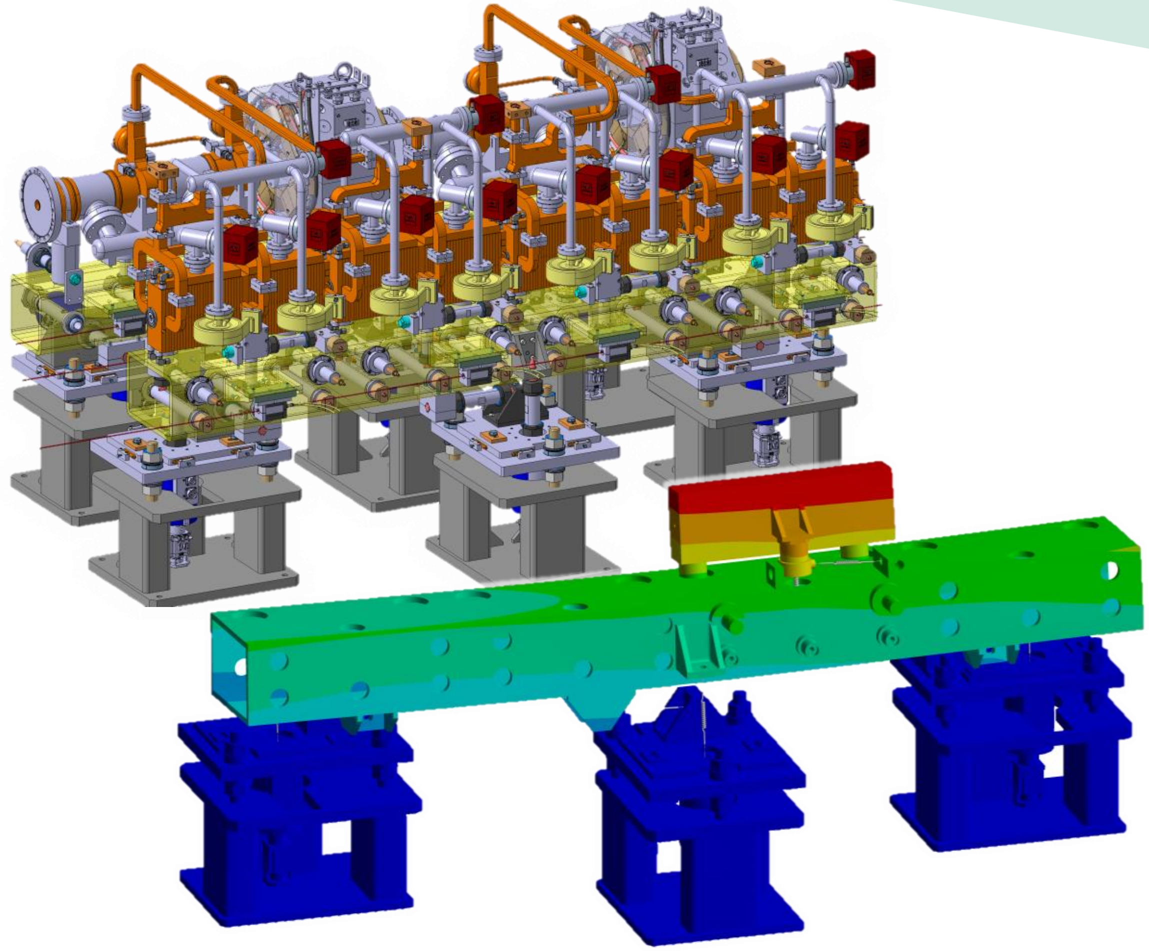


Left/Below: The choke mode flange klystron module

Right/Below: The L-waveguide klystron module and the analysis of the single-height WR-90 used to verify the adjustment range

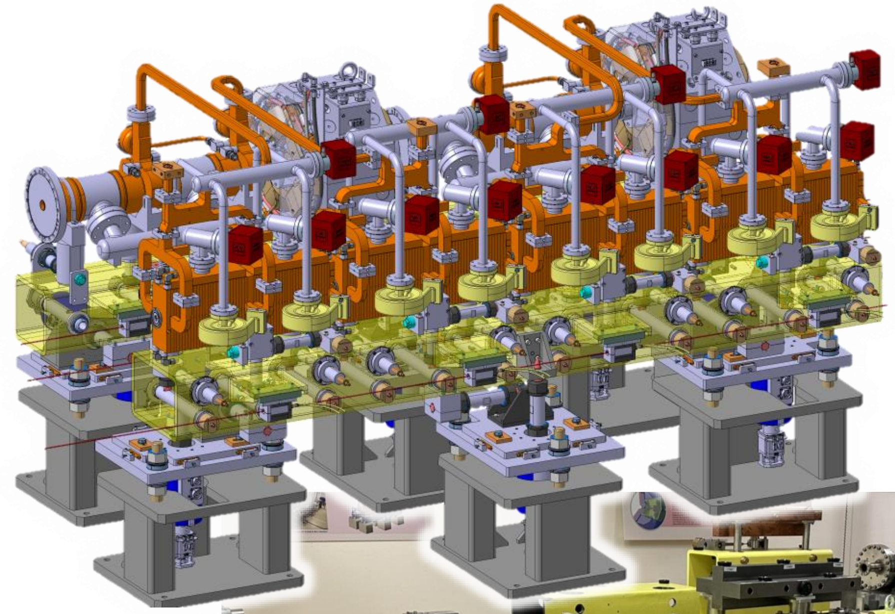
Future Work

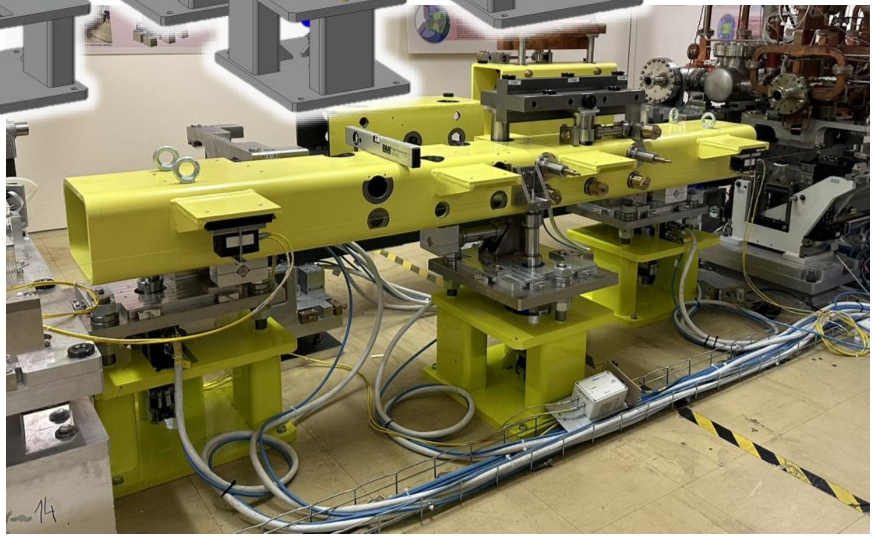
- Stability testing and comparison to the analysis
  - Verifying the module meets the alignment and stability requirements
- Industrialisation and cost optimisation studies
- Environmental impact and reduction studies
  - Materials used for the supports



Summary

1. Testing of the structure prealignment system has demonstrated the ability to position the SAS to less that 1µm over ±1.4mm
2. Initial testing of the active alignment system has shown a positional accuracy of <41µm and <145µrad over ±1mm without feedback, and <9µm when using the WPS for positional feedback
3. Stability testing of the system is due to take place early next year
4. Design and optimisation of the Two-beam and Klystron modules has been continued





Thanks for listening

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Bonus slides

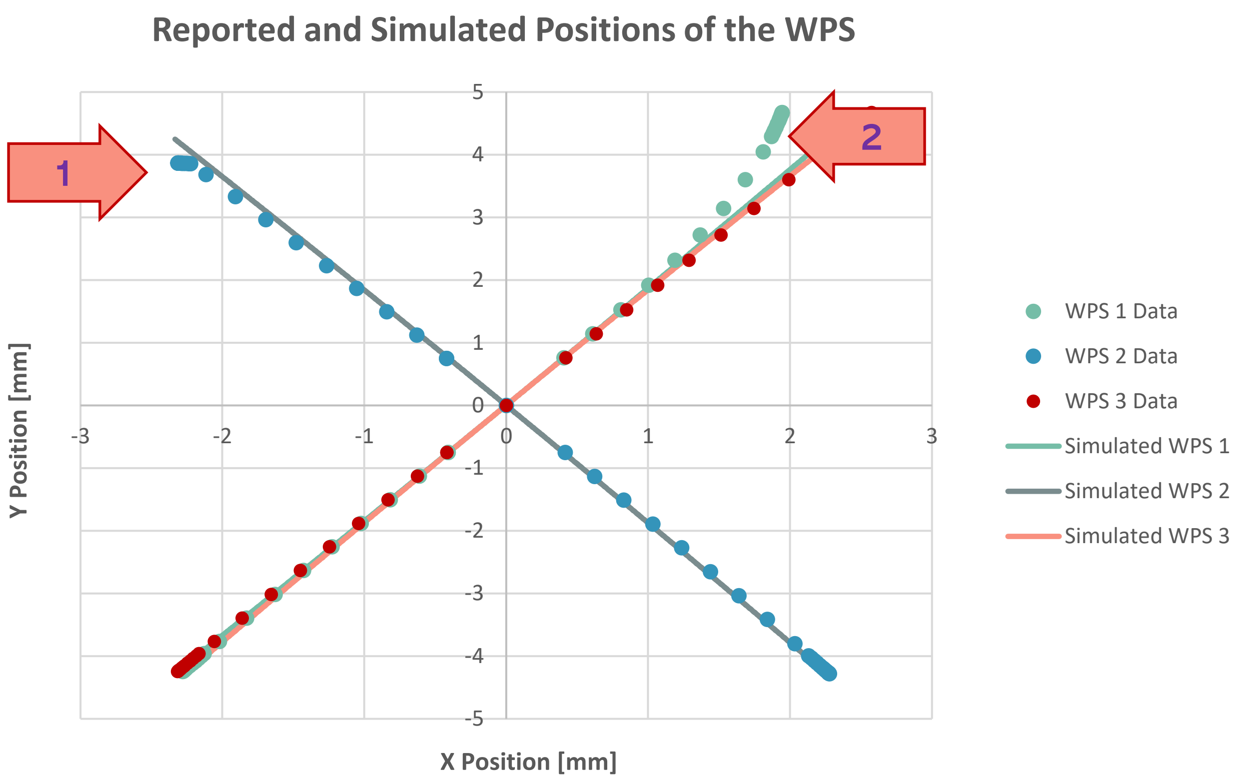
Active Alignment Testing

Calculating the girder coordinate system transformation averages the translation of the individual sensors.

In some extreme cases, limitations of the positioning system can be identified:

1. Rolling increases the total displacement as the beam position is above the supports. This causes one of the sensors (1) to go out of the measurable range.
   - 8mm of vertical translation, greater than the 6mm actuator range
2. One of the sensors (2) differs from the simulation, presumably due to a mechanical limit or impingement
   - This is particularly noticeable at the extremes of travel

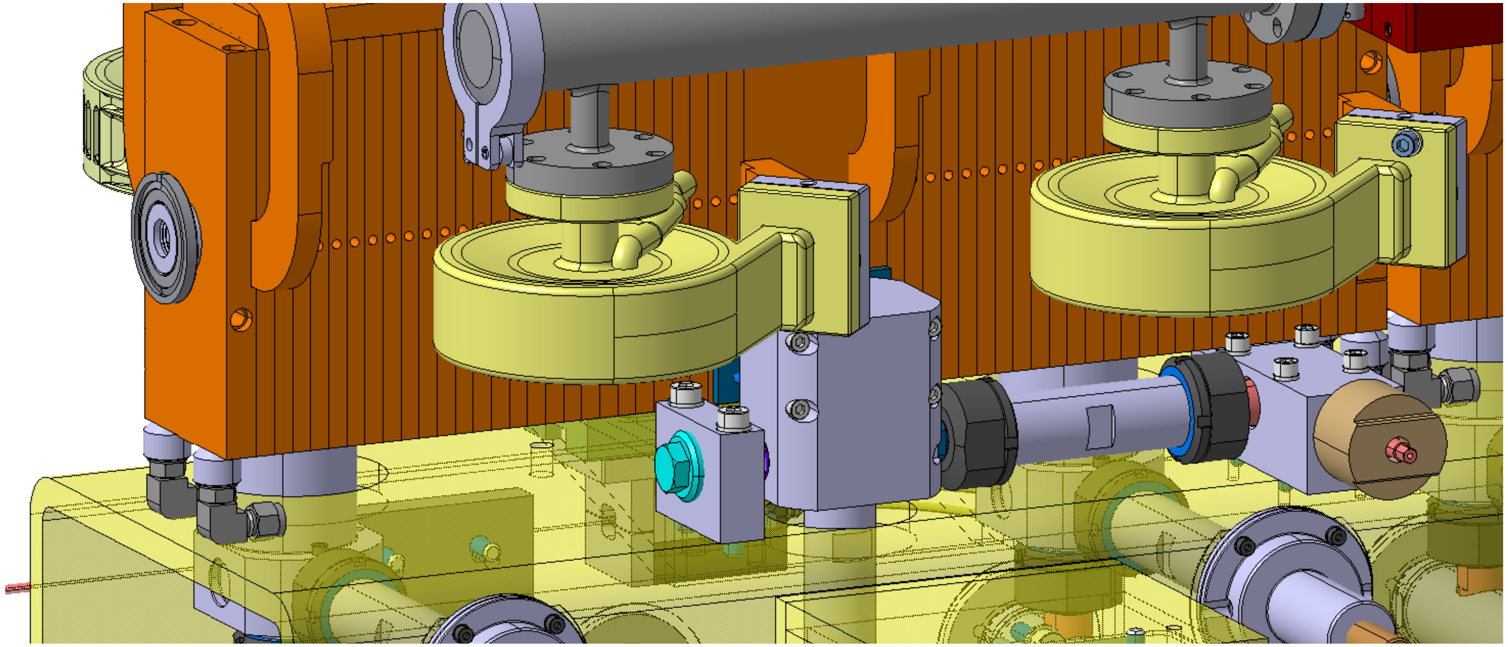
This is not the intended operation of the active alignment system!

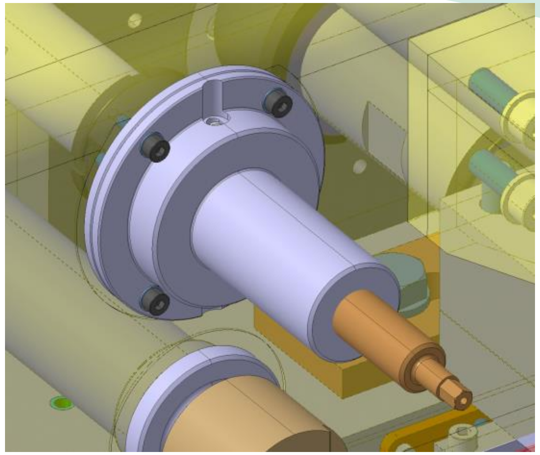


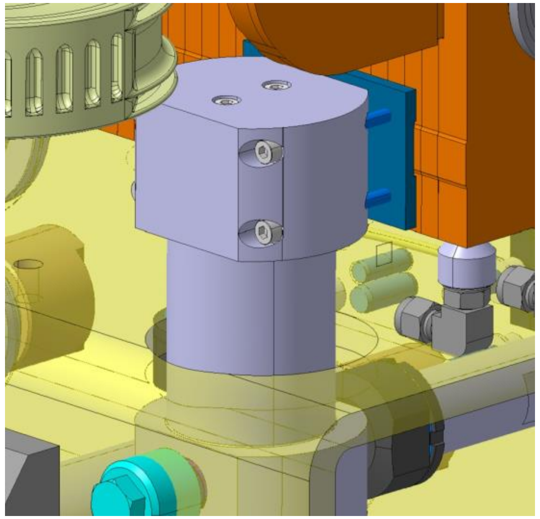
The X-Y data recorded directly from the wire sensors during a roll test, and the simulated values

Design Modifications for V5

- Modified vertical joint support so accommodate the rectangular disc structure mounted vertically between the joints.
- The differential thread is modified so that the pin can be inserted vertically, simplifies the installation

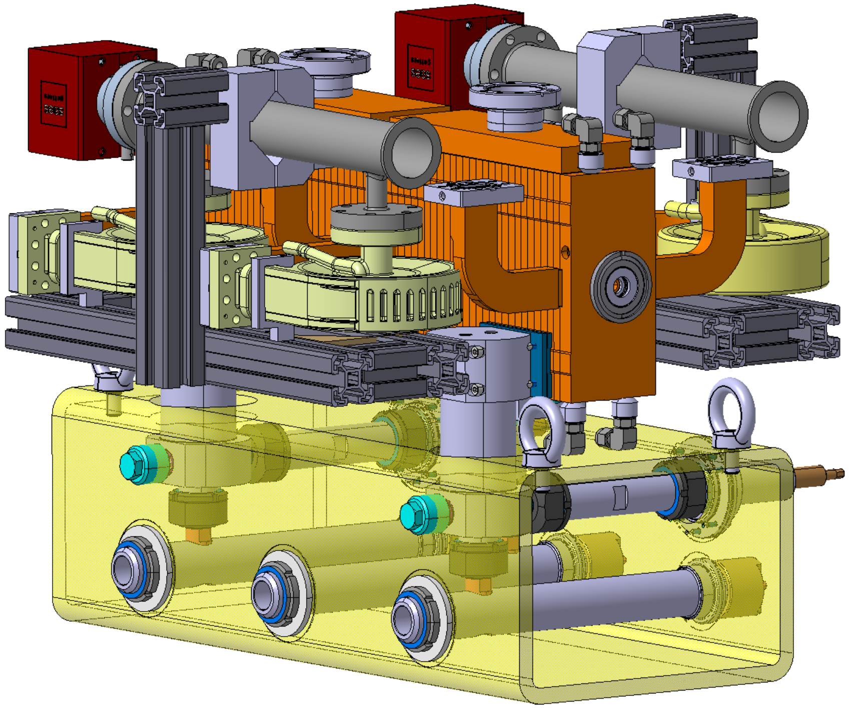




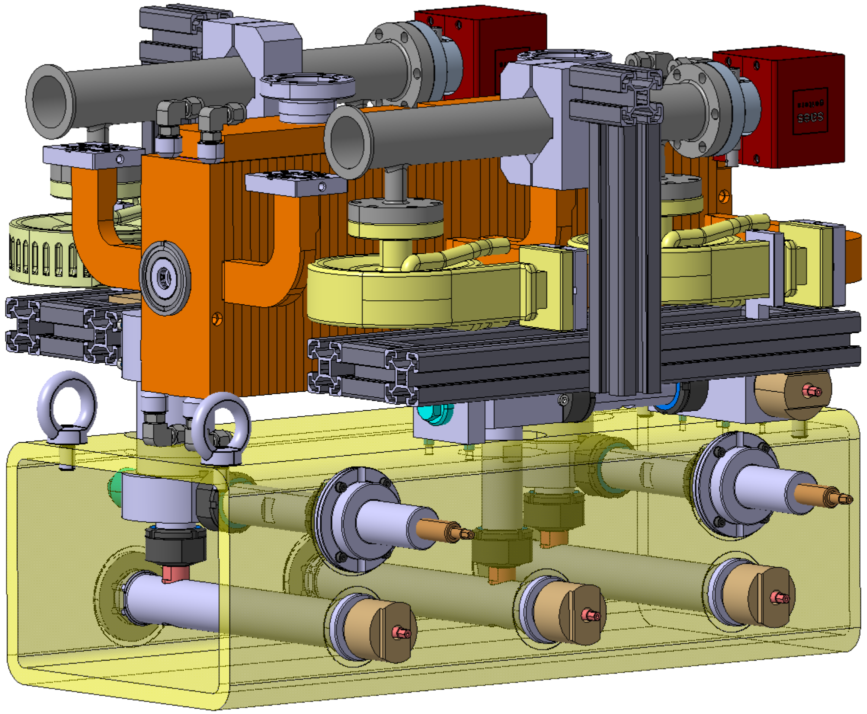


Waveguide & Component Supports

We can install a small support frame on either side of the alignment platform for RF-loads and Vacuum Components.

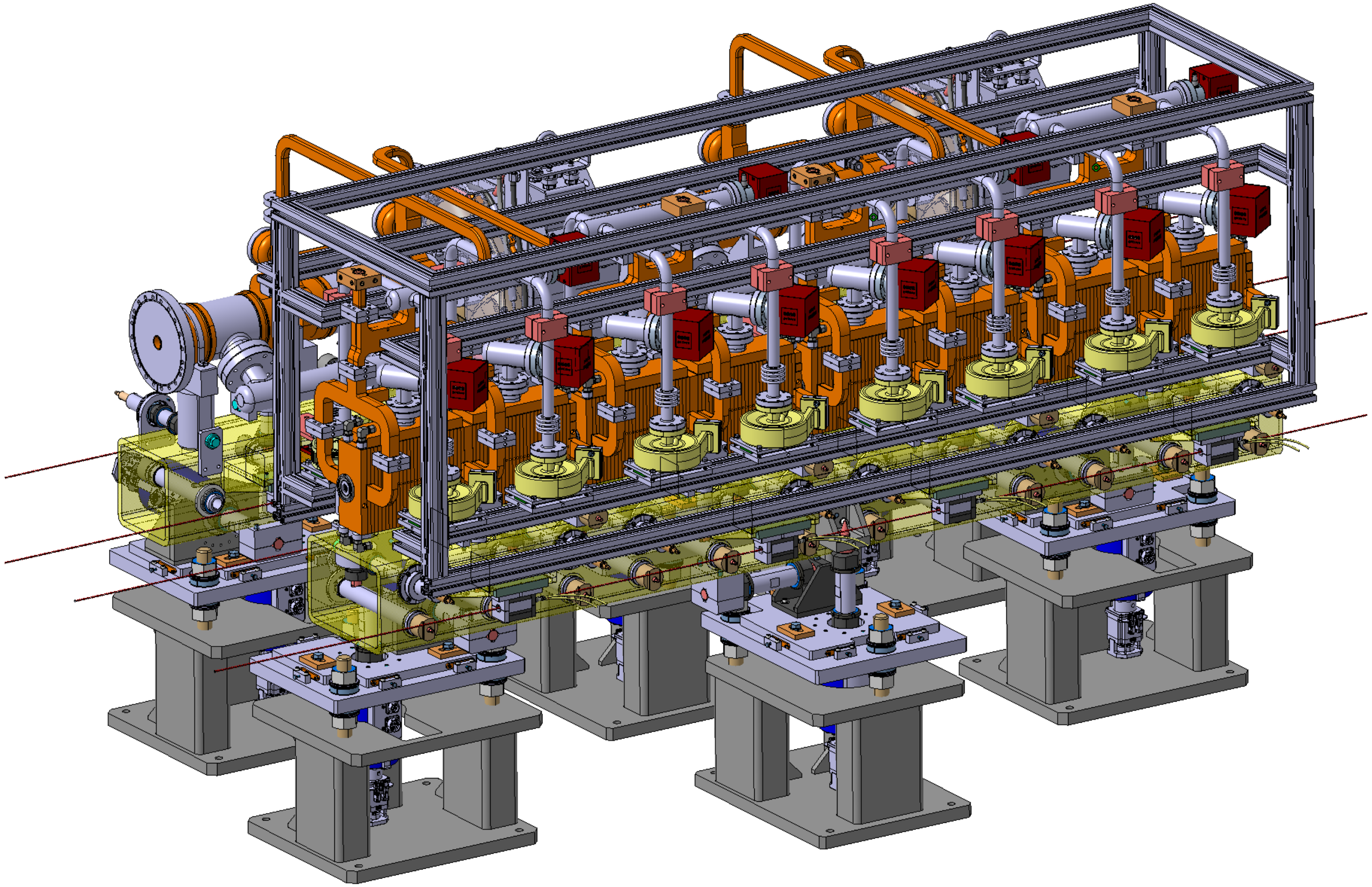


- This maintains the alignment capability of the platform, without increasing the weight on the structure itself
- Slightly increases the mass supported by the platform
  - Could be bad for vibration



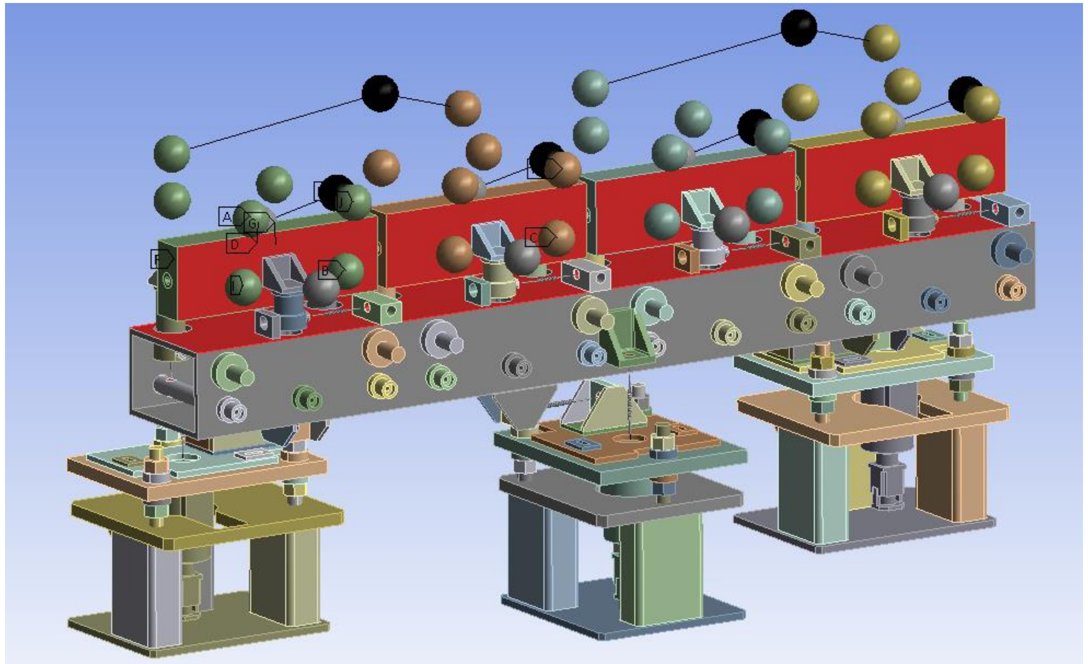
Waveguide & Component Supports

- Can mount a support frame over the whole module.
- The RF loads could be installed after an initial alignment stage (~100μm) and mounted on individual sprung supports
- Take most of the weight without constraining the final alignment
- The vacuum manifold can be hard mounted to the support frame, using bellows before the RF loads.
    - Reduces the mass on the Structure Alignment Platform, which improves the vibration performance.



Waveguide & Component Supports

Vacuum manifold & pump mass attached to the girder

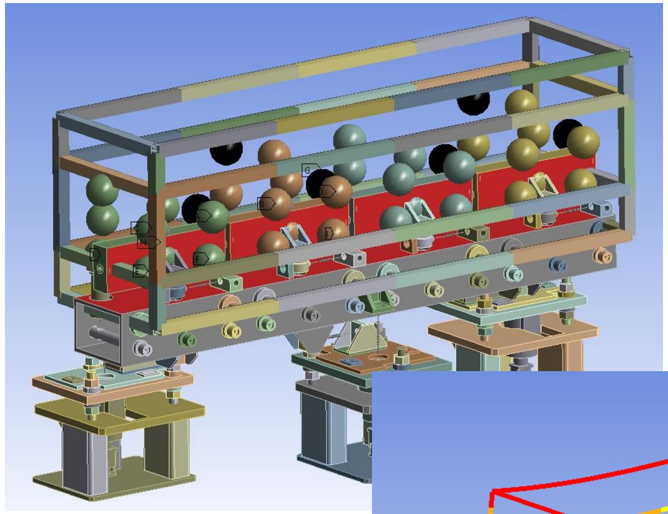


Moderate increase in stiffness

	Mode	Frequency [Hz]
1	1.	58.695
2	2.	60.647
3	3.	79.532
4	4.	100.94
5	5.	125.41
6	6.	130.64

	Mode	Frequency [Hz]
1	1.	63.136
2	2.	65.364
3	3.	107.93
4	4.	134.53
5	5.	141.33
6	6.	144.31

Frame analysis



Very similar vibration behaviour for the same mode

	Mode	Frequency [Hz]
1	1.	51.92
2	2.	55.47
3	3.	60.185
4	4.	64.04
5	5.	64.347
6	6.	65.192