Structural Stability and Instrument Installation of a 10m interferometer in the Beecroft Building

2nd Terrestrial VLBAI Workshop

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2024-04-04

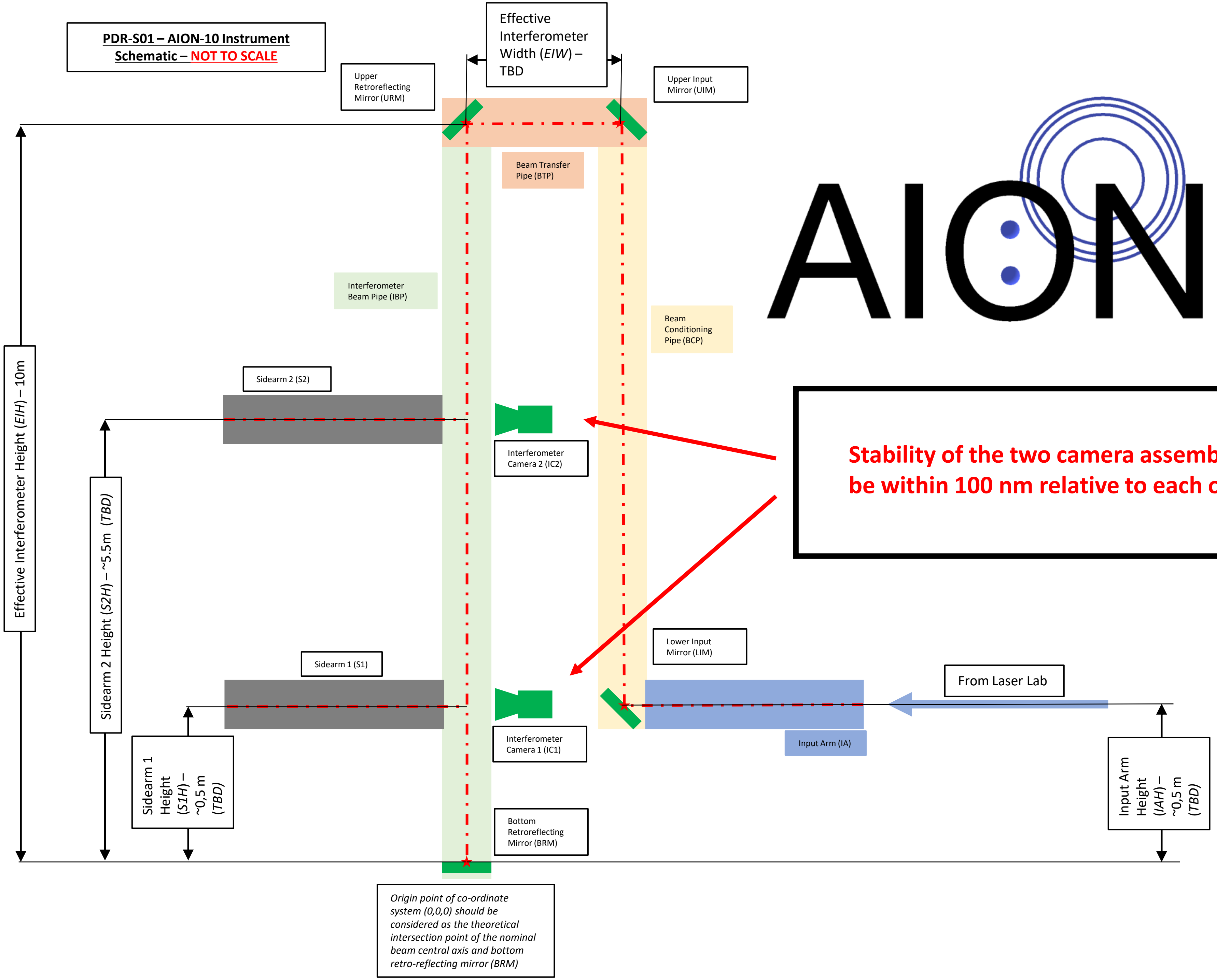
Outline

- Structural Stability
  - Overview of AION-10 structure design and stability requirements
  - Support of Structure
  - Modal and Response Analysis
  - Further Analysis and Prototyping
  - Strategies for Vibration Control
- Instrument installation

Structural Stability

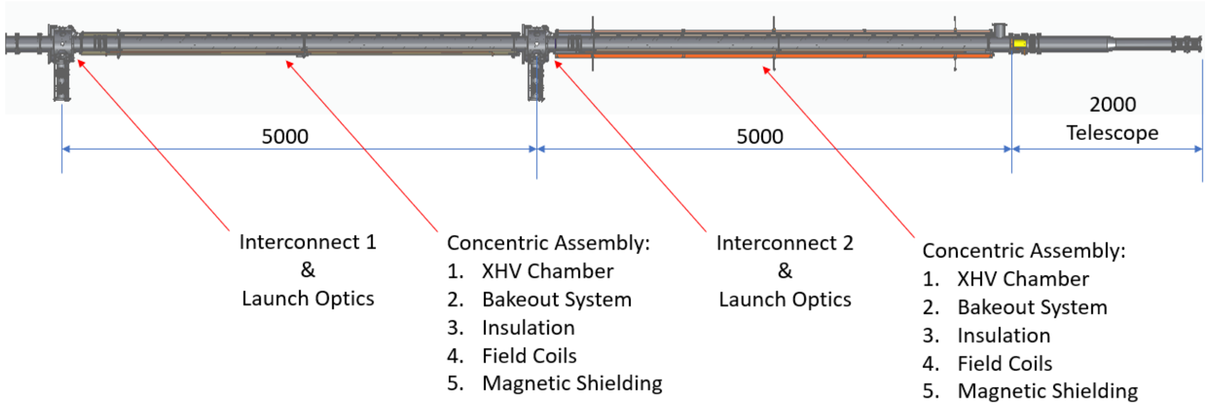
- AION-10 Structure Design and Stability Requirements
- Support of Structure
- Modal and Response Analysis
- Further Analysis and Prototyping
- Strategies for Vibration Control

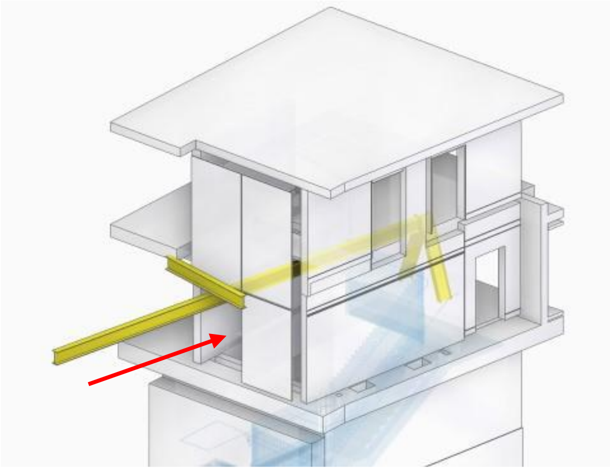
PDR-S01 – AION-10 Instrument Schematic – NOT TO SCALE



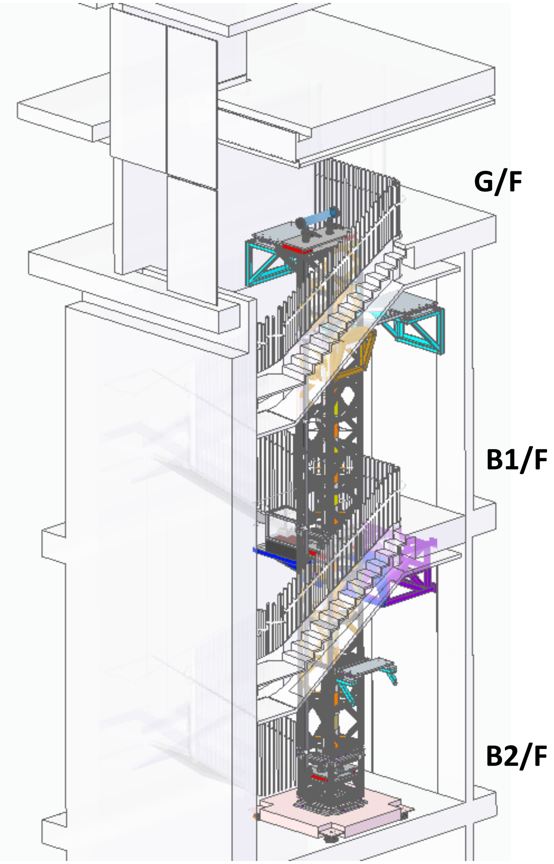
Stability of the two camera assemblies (CA1 and CA2) must be within 100 nm relative to each other whilst taking data.

AION-10 Instrument layout and Beecroft Building





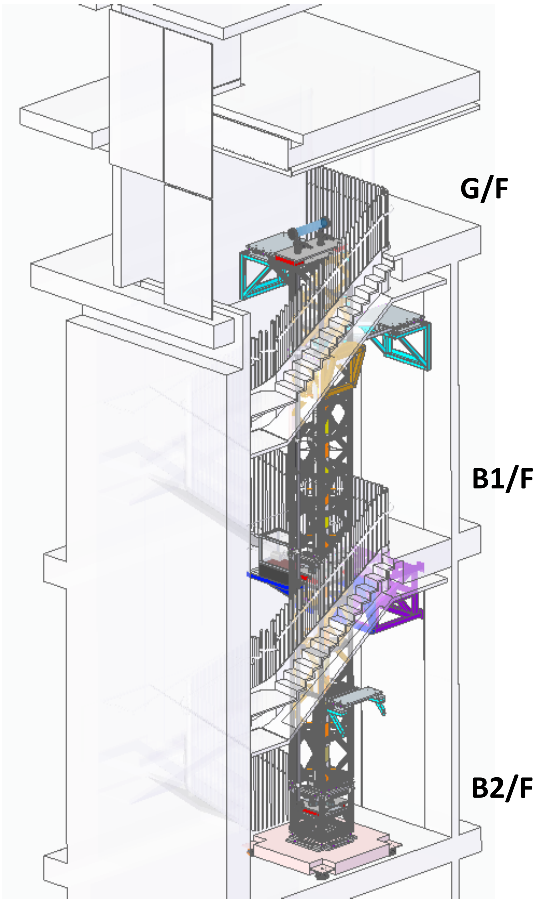
Crane in through a removed windowpane on the G/F of Beecroft Building

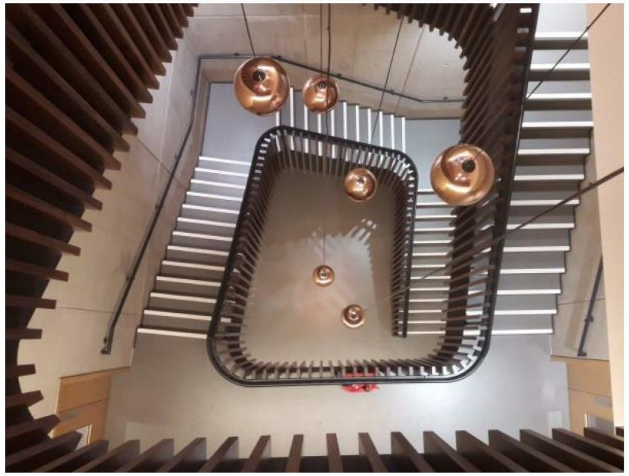


- AION-10 to be installed in Beecroft Building in Oxford
- Instrument encased in aluminium frame support tower
  - Provide stability support and space to attach things
  - Protect instrument during transportation and installation
- Instrument and support tower to be split into several modules for ease of installation
  - Module assembly to be done elsewhere and completed assemblies to be transported into Beecroft
  - Magnetic shield for each XHV Chamber needs to be kept as a single unit to achieve magnetic shielding requirements
- Modules need to be transported into the building with a crane system

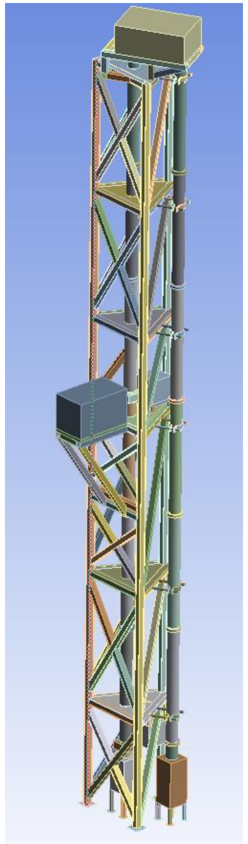
AION-10 Structure Design and Stability Requirements

Site for AION-10

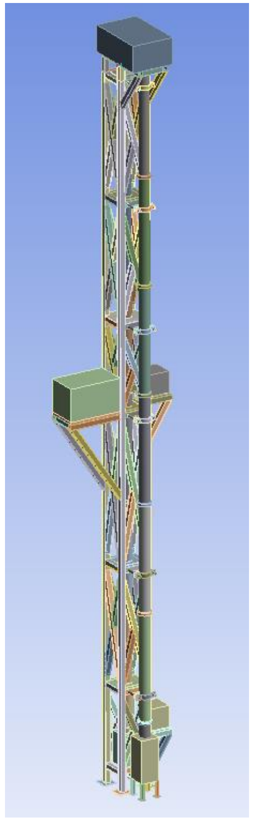




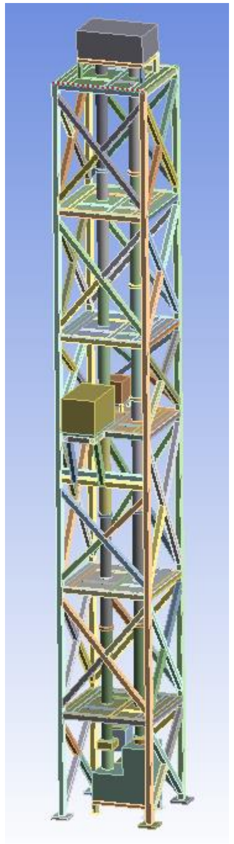
AION-10 Structure Design and Stability Requirements



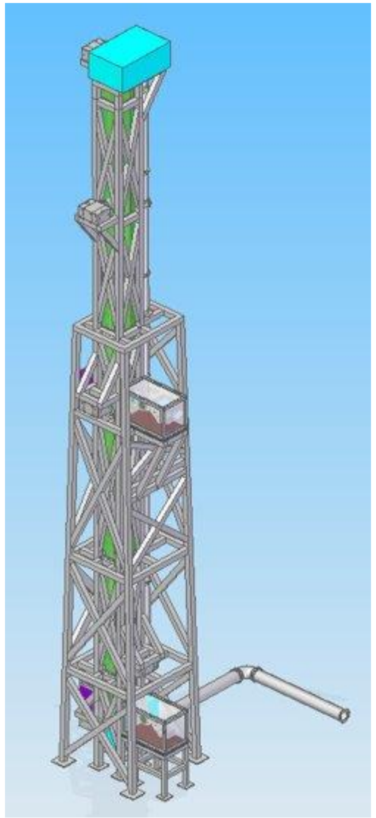
Triangle



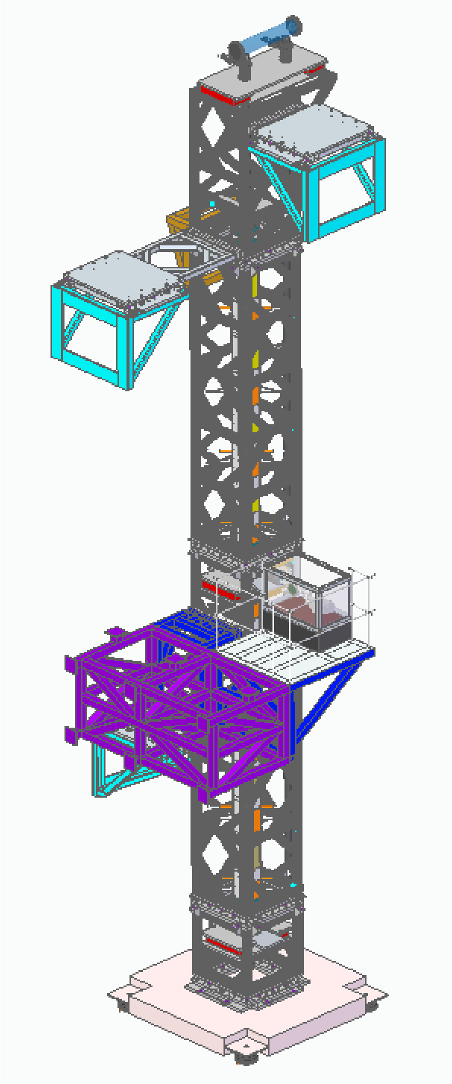
Thin Tower



Large Tower



Non-Uniform

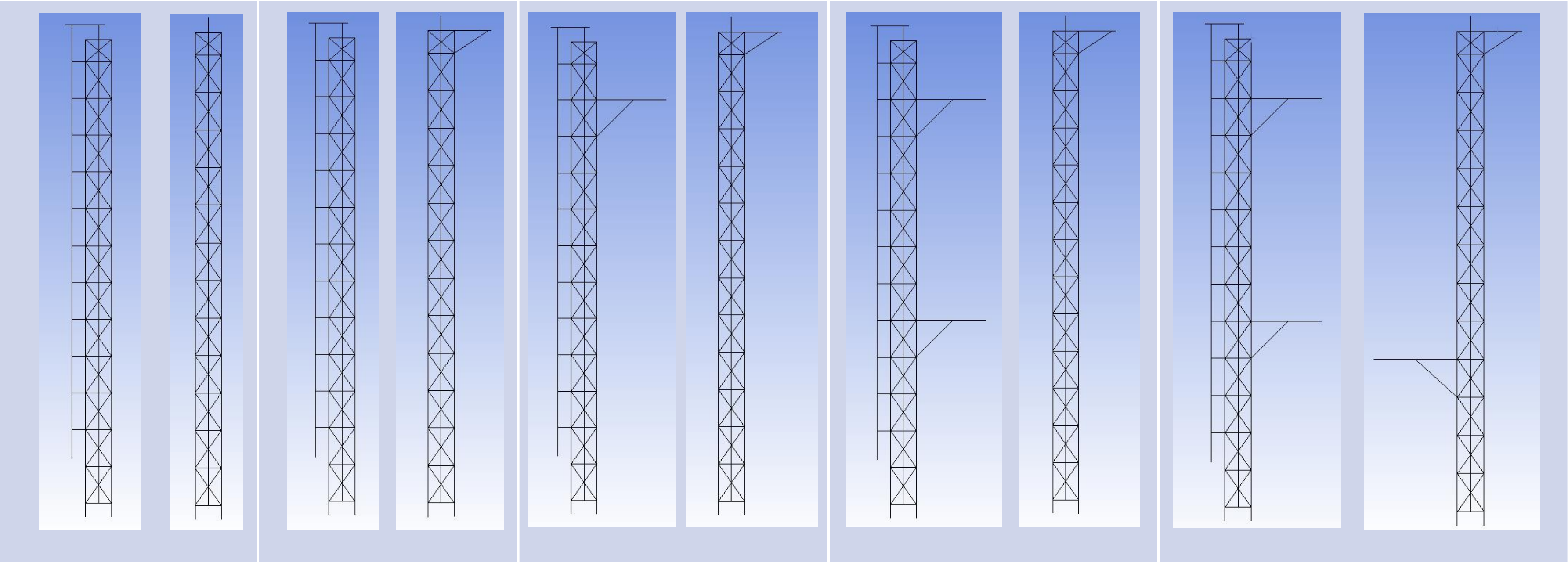


Proposed Design

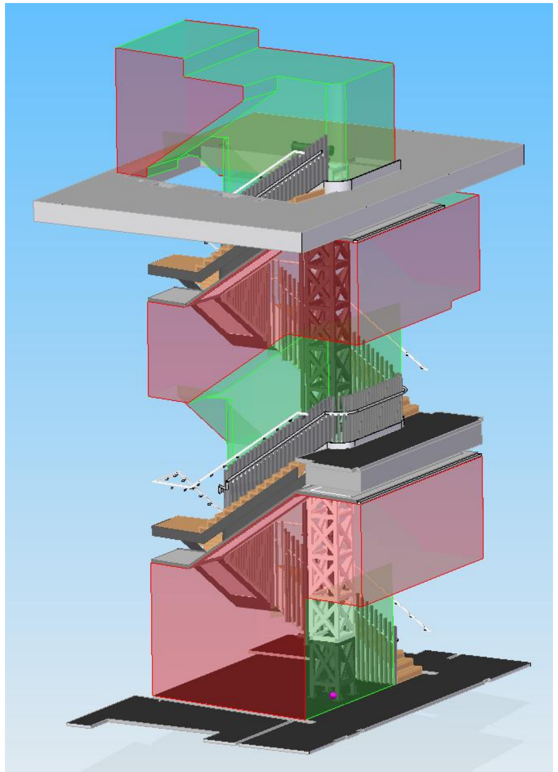
Support of Structure

Comparison of Support

Case 0	Case 1	Case 2	Case 3	Case 4
~ 2.5 Hz	~ 13.5 Hz	~ 15 Hz	~ 20 Hz	~ 30 Hz

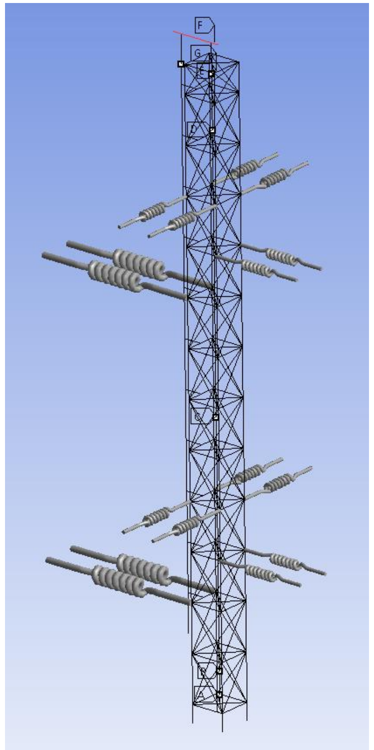


Lower 1st mode frequency → Higher 1st mode frequency



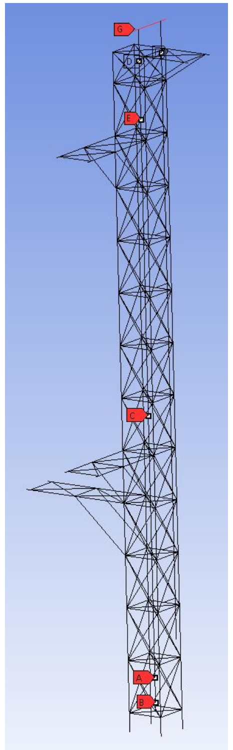
Support of Structure

Tensioned Cable and Rigid Support



Tensioned cables

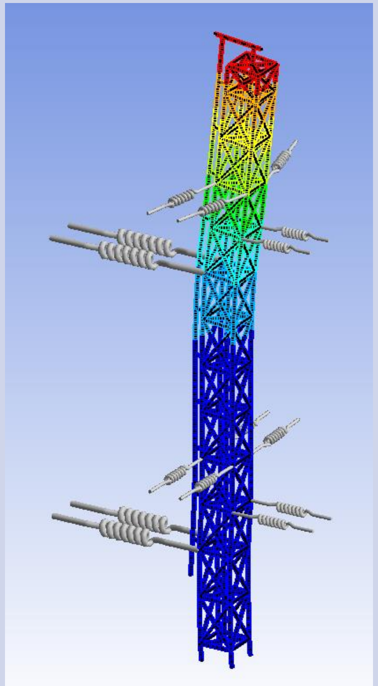
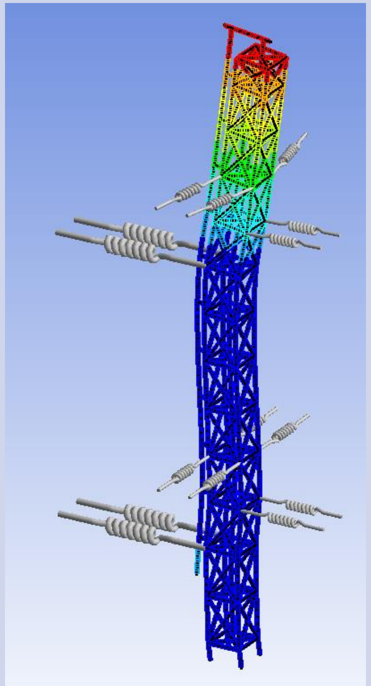
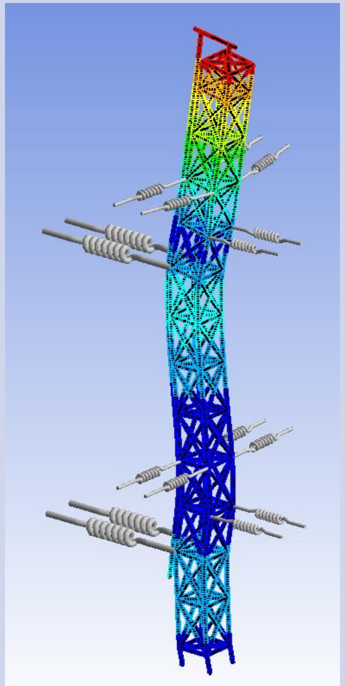
- Lighter
- Causes tower deformation
- Requires force balancing, which gives less choices in cable locations for reinforcing the tower
- Tower stiffness generally lower
- Potentially damps vibration source from side walls



Rigid structures

- Heavier
- Need to take into account installation tolerance when coupling tower to side walls
- No force balancing required
- Tower stiffness generally higher

Support of Structure

10 mm/52.6 kN	20 mm/204 kN	70 mm/2453 kN
		

~ 5.29 mm ~ 10.98 mm ~ 48.16 mm

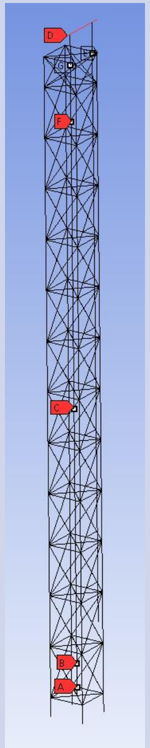
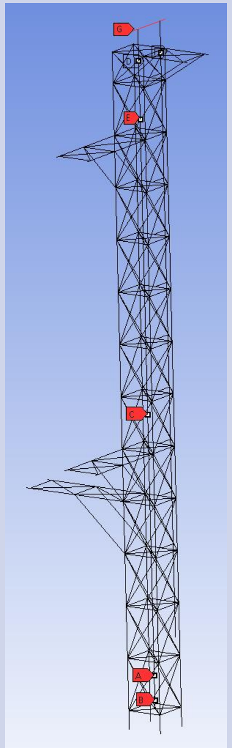
Lower max. total deformation → Higher max. total deformation

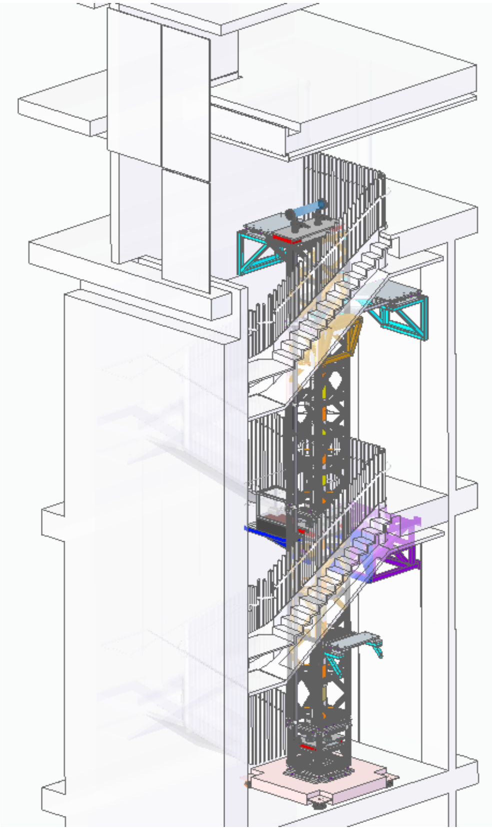
~ 10 Hz ~ 14 Hz ~ 20 Hz

Lower 1st mode frequency → Higher 1st mode frequency

Support of Structure

Tensioned Cable and Rigid Support

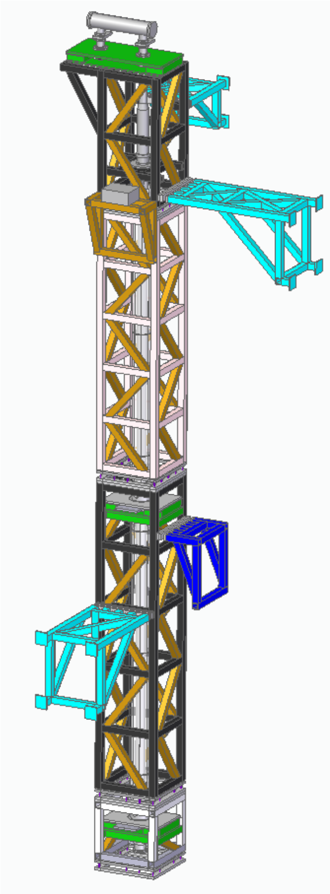
Free-standing	Tensioned cables	Rigid structures
		
~ 2.5 Hz	~ 10 Hz	~ 30 Hz



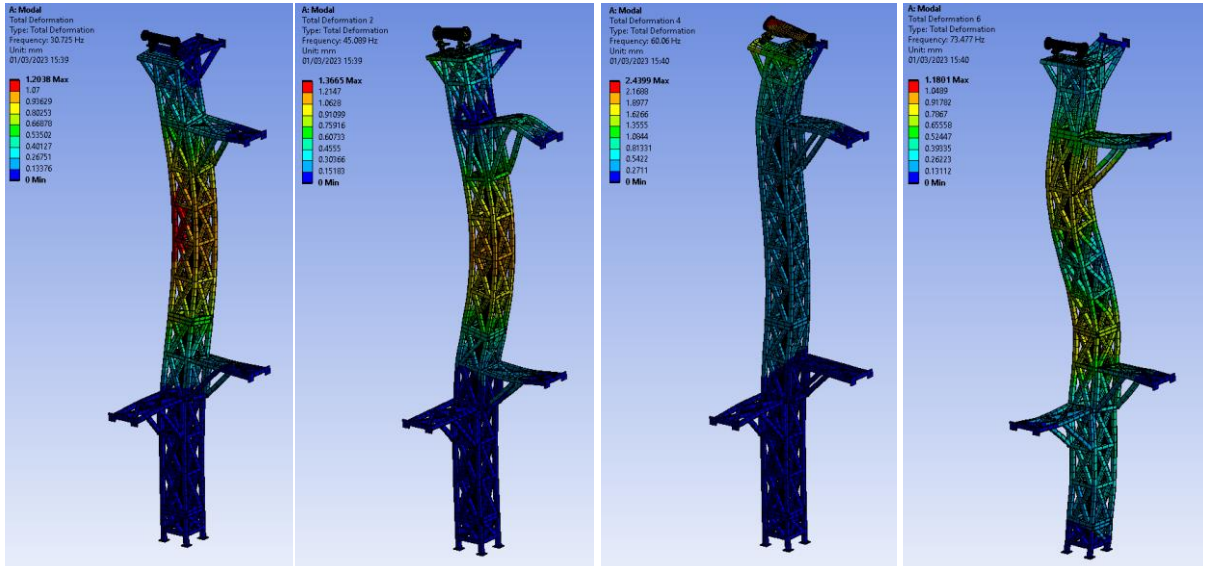
Lower 1st mode frequency → Higher 1st mode frequency

Modal and Response Analysis

Modal Analysis



Mass (kg)	4027.4
Nominal Footprint (m)	0.9 x 0.9
1st Mode (Hz)	28.6
2nd Mode (Hz)	30.3
3rd Mode (Hz)	34.9
4th Mode (Hz)	36.3
5th Mode (Hz)	37.5
6th Mode (Hz)	37.9
7th Mode (Hz)	39.9
8th Mode (Hz)	41.8
9th Mode (Hz)	45.3
10th Mode (Hz)	46.7



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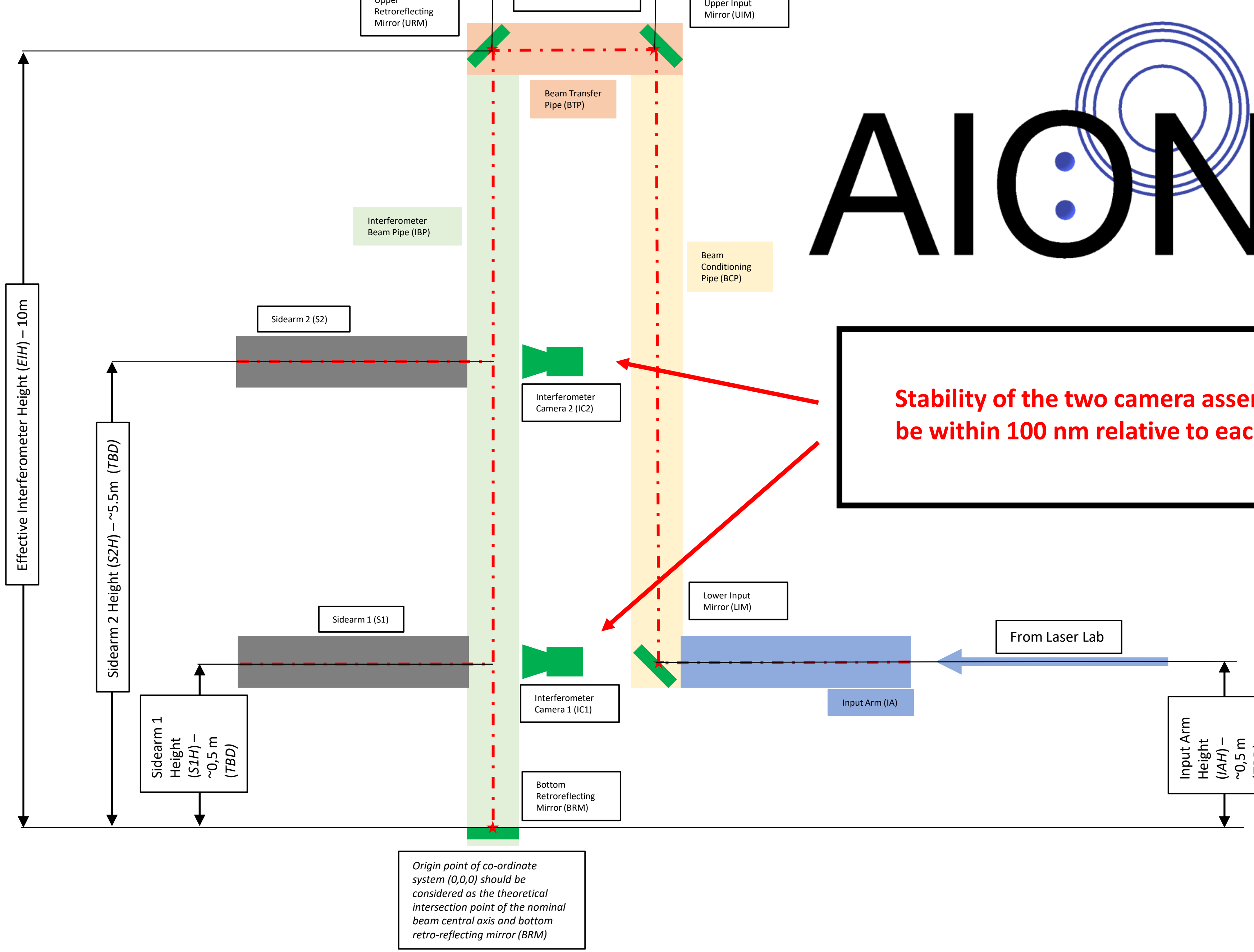
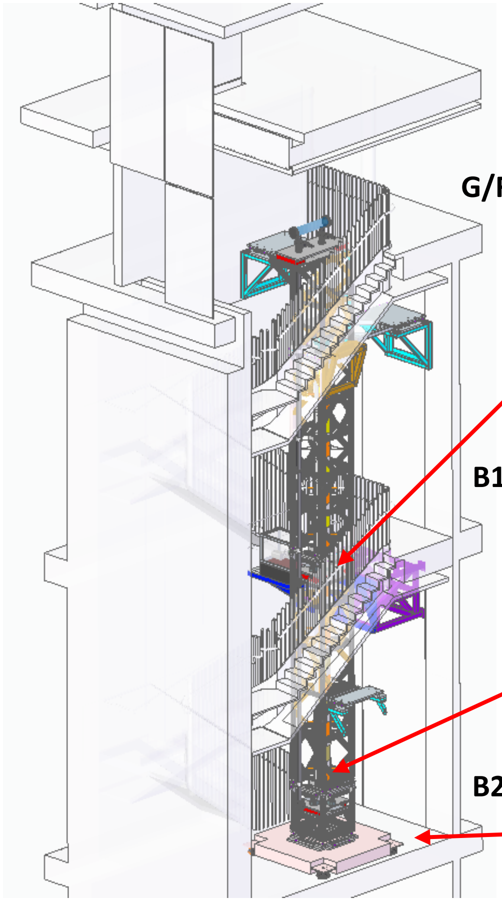


AION

Stability of the two camera assemblies (CA1 and CA2) must be within 100 nm relative to each other whilst taking data.

Modal and Response Analysis

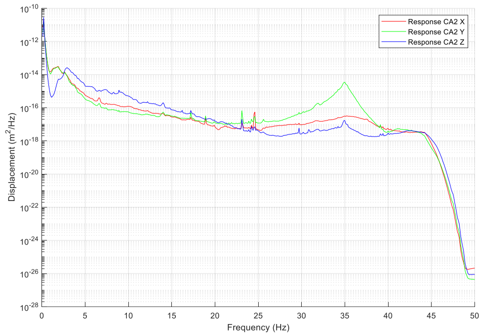
Response Analysis



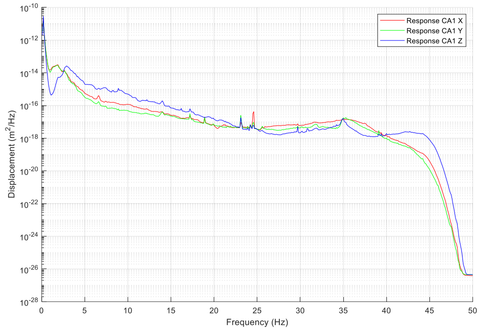
G/F

B1/F

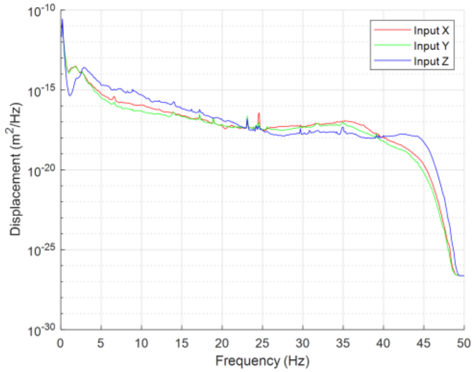
B2/F



Upper Camera

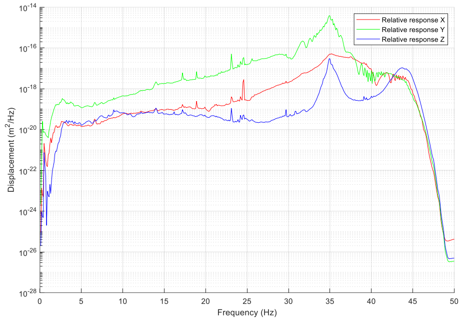


Lower Camera



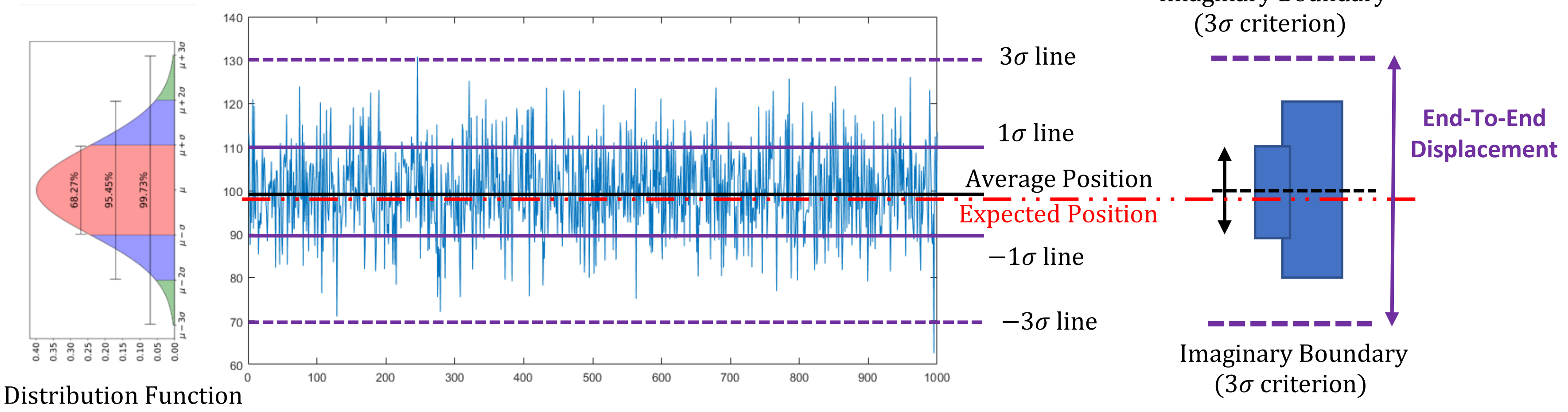
Building Vibration
(Input)

Camera Relative



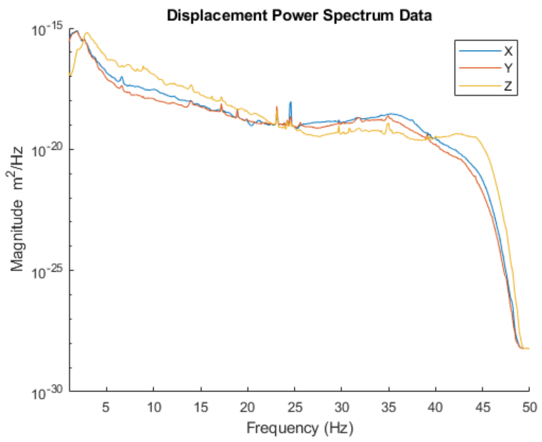
Modal and Response Analysis

Response Analysis



$$RMS_{x(t)} = \sqrt{\int_{\omega_1}^{\omega_2} S_{disp}(\omega)d\omega}$$

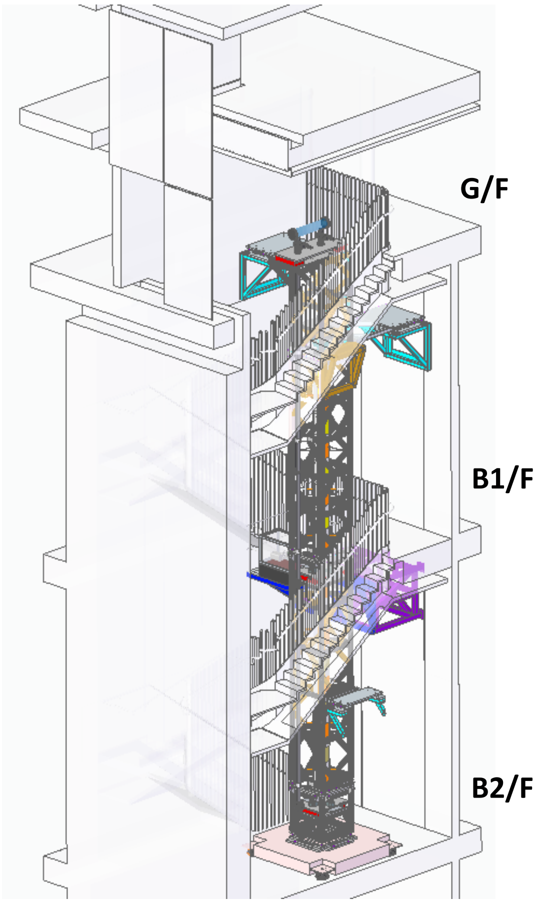
$$\sigma_x = RMS_{x(t)}$$



End-to-end displacements

Active vibration isolation	Direction	Input end-to-end displacement (nm)	Absolute end-to-end displacement of lower camera assembly (nm)	Absolute end-to-end displacement of upper camera assembly (nm)	Relative end-to-end displacement between two camera assemblies (nm)
No	X	1257.1	1258.2	1261.9	92.33
No	Y	1197.5	1198.1	1273.0	425.28
No	Z	1212.4	1215.1	1218.1	41.29
Yes	X	189.32	189.35	189.42	0.125
Yes	Y	177.01	177.03	177.27	0.517
Yes	Z	49.57	49.59	49.61	0.0514

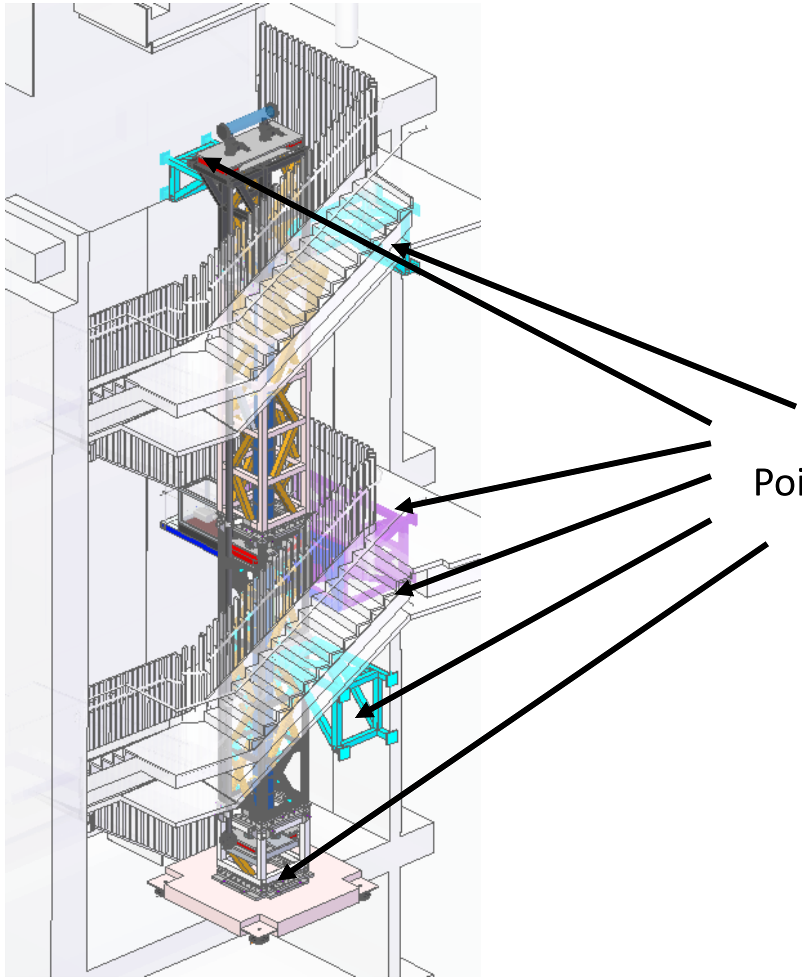
Response Analysis



Challenges

- Uncertainties of analysis associating with material, manufacturing and assembling.
- Single vibration input setting for structure with multiple support points
- Selection of damping factor.
- Impact of mega-structure (building).

Further Analysis and Prototyping

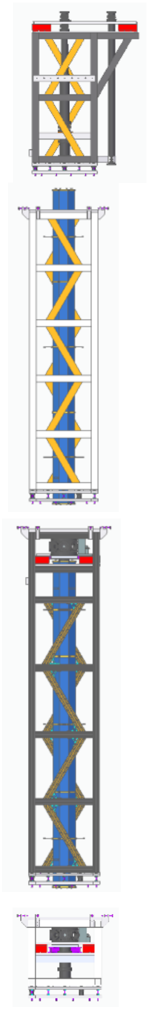


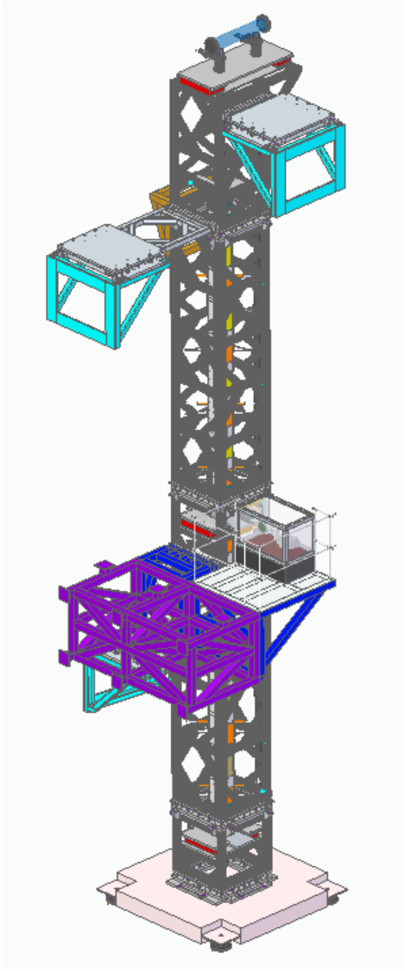
Points of Measurement

Additional Vibration Survey

- Vibration measurement for multiple points in the stair well.
- Synchronised acquisition of data across points to preserve relationship of vibration.
- Multi-input vibration model.

Further Analysis and Prototyping



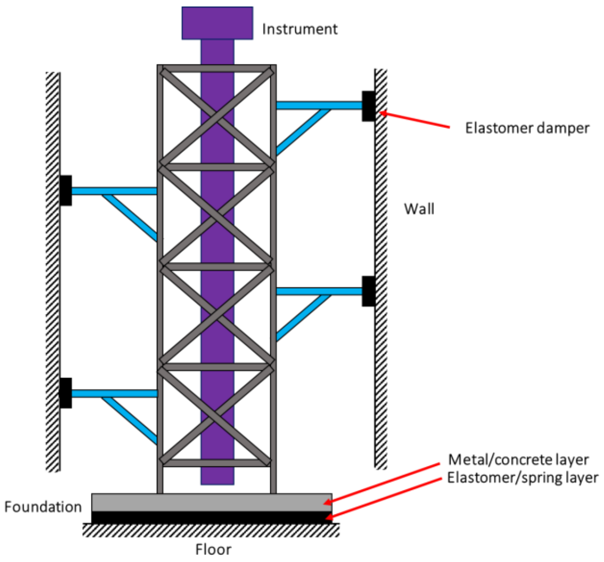


Prototyping of Tower Section

- 1/3 of actual size.
- Validate analysis model (small scale).
- Study damping factor.
- Test response.

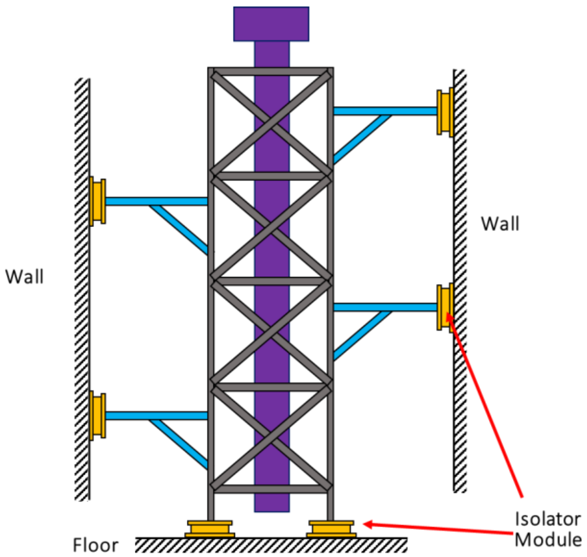
Strategies for Vibration Control

Passive Damping



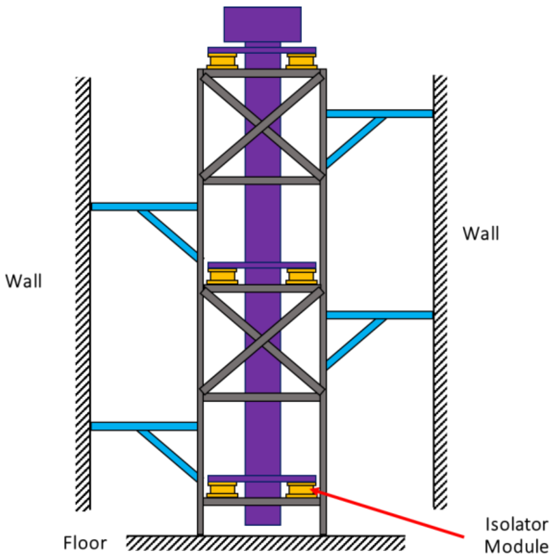
- Base foundation with stiff large-mass layer and elastic layer
- Elastomer dampers between tower and floor, walls

Active Vibration Isolation



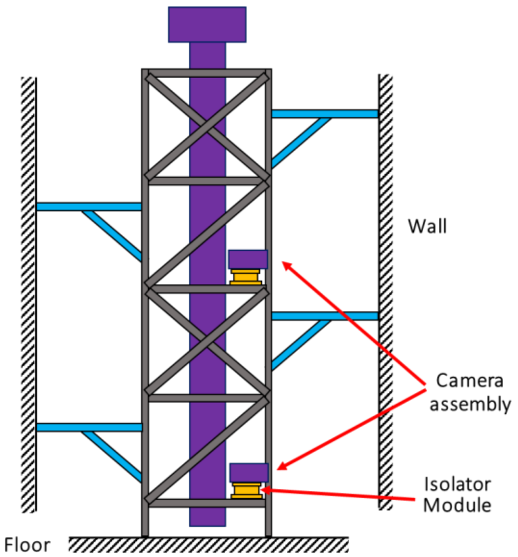
Isolation of entire tower

- Isolation units between tower and floor, walls



Isolation of instrument only

- Isolation units between instrument and tower

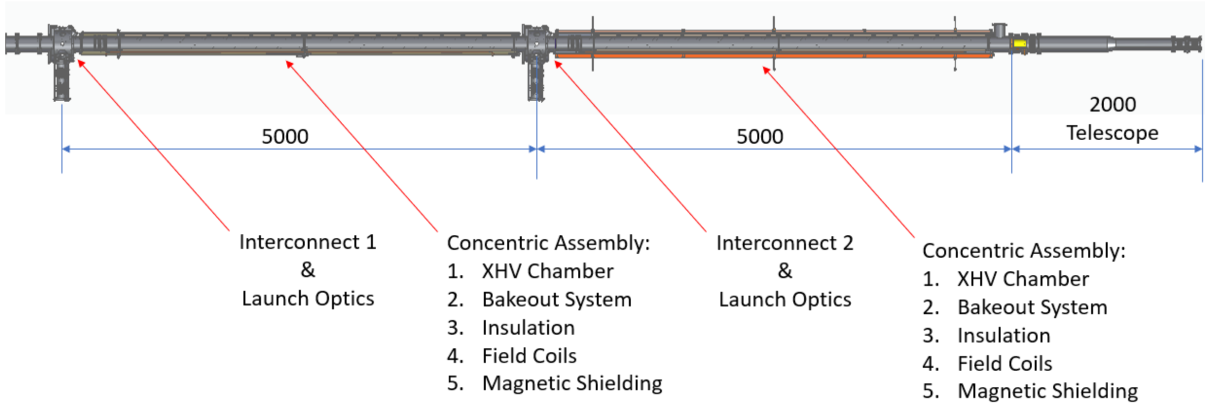


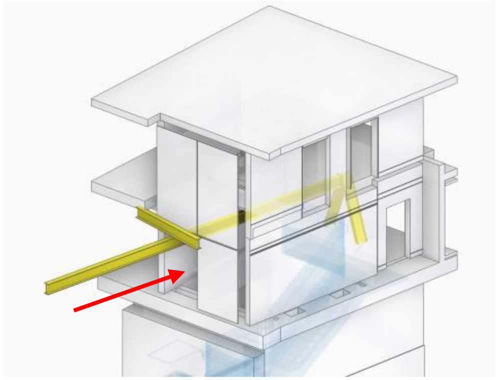
Isolation of critical components only (e.g. cameras, optics)

- Critical components mounted onto isolation units

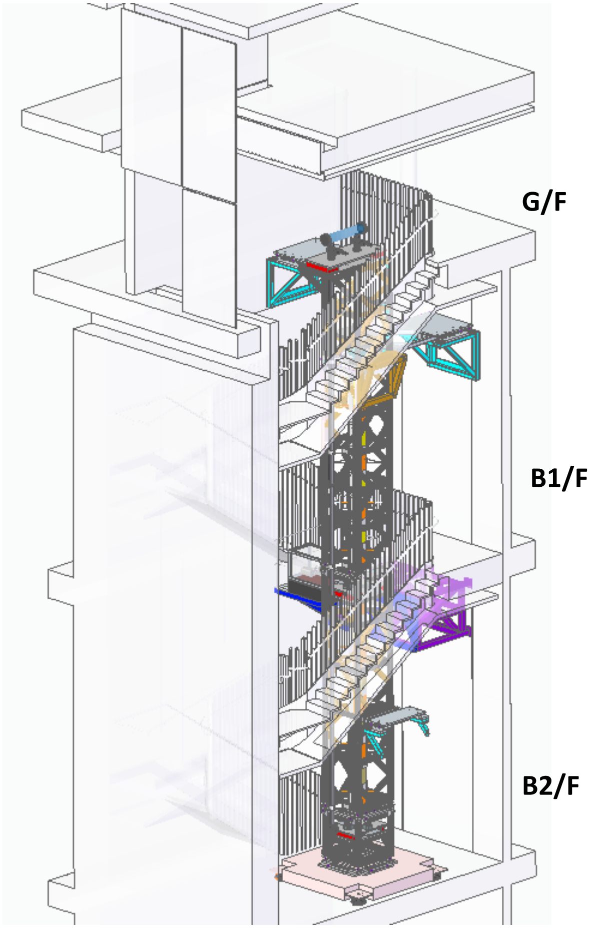
Instrument Installation

AION-10 Instrument layout and Beecroft Building





Crane in through a removed windowpane on the G/F of Beecroft Building



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- Instrument and support tower to be split into several modules for ease of installation
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  - Magnetic shield for each XHV Chamber needs to be kept as a single unit to achieve magnetic shielding requirements
- Modules need to be transported into the building with a crane system

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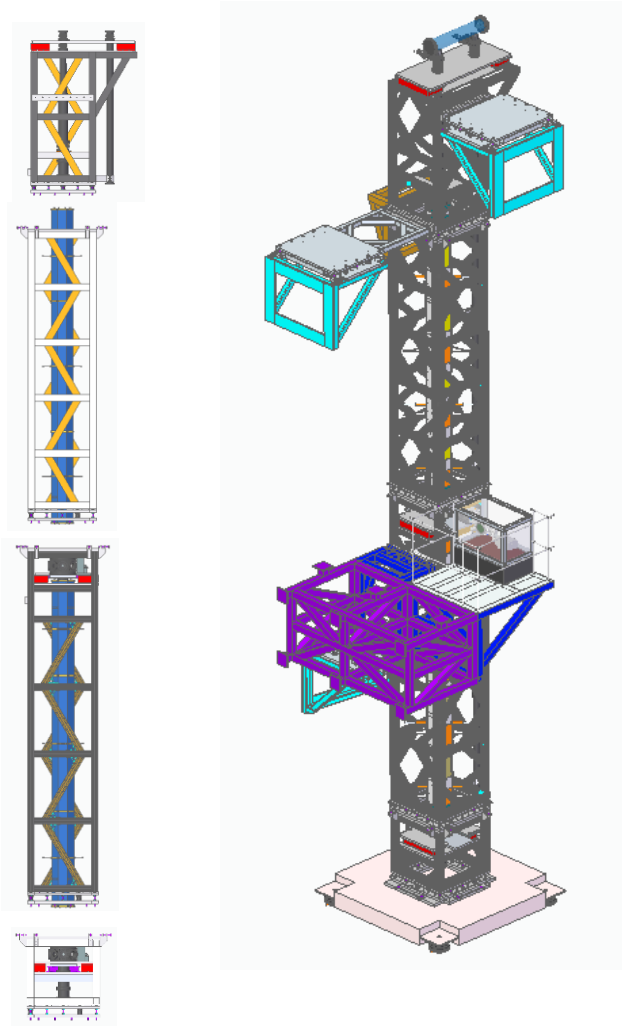
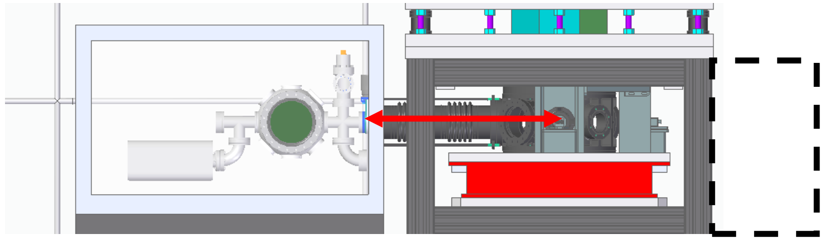
Tower footprint and module split

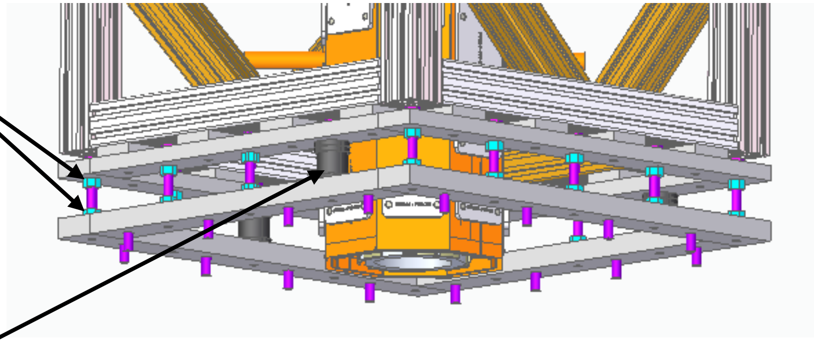




- Preliminary max. allowable dimensions for craning 1 x 1 x 5 m
- Tower footprint nominal 0.9 x 0.9 m built with aluminium profiles
  - External frames added onto the tower after installation -> increase space without increasing footprint
- Split into 4 modules (tentative)
  - Base: lower mirror chamber + lower interconnect (Length: 1 m)
  - Lower main: vacuum pipe module + upper interconnect (Length: 5 m)
  - Upper main: vacuum pipe module (Length: 4.5 m)
  - Top: T-joint for ion pump + telescope (Length: 2.5 m)
- Side support frames installed separately from the tower
- Concrete inertia base installed separately beforehand to act as inertial mass damper

Tower module interfaces

Double nuts on bolts to fix adjusted level

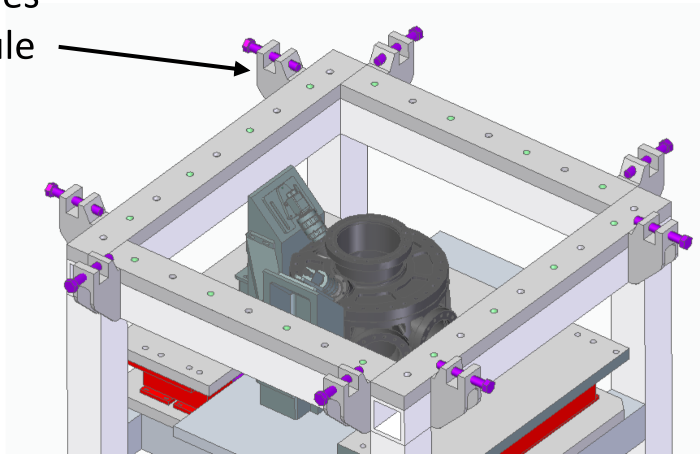


Levelling adjusters for adjusting levelling of tower module during installation

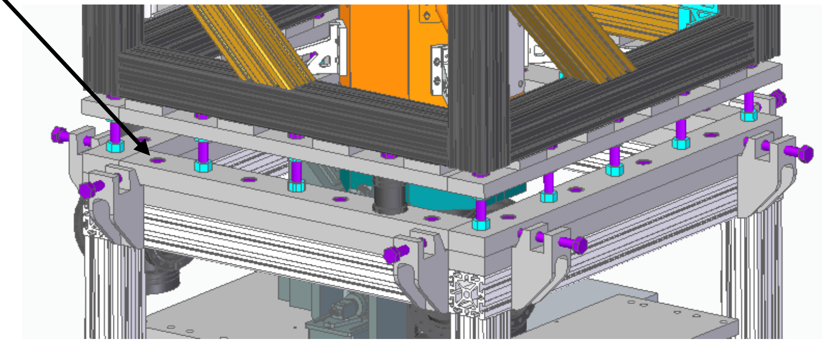
A separate, finer levelling and position adjustment for the instrument

Removable position adjustors on all 4 sides

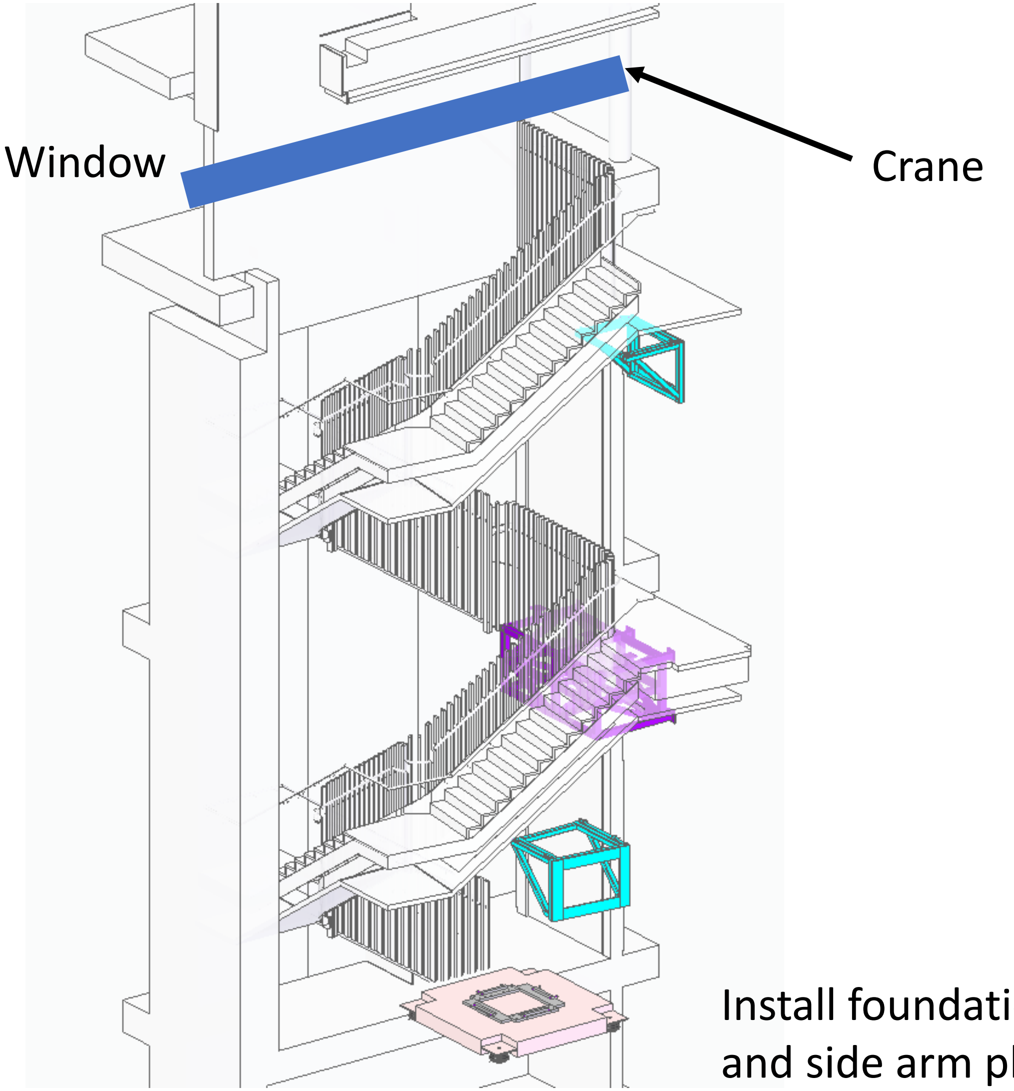
- Adjust lateral position of tower module above during installation



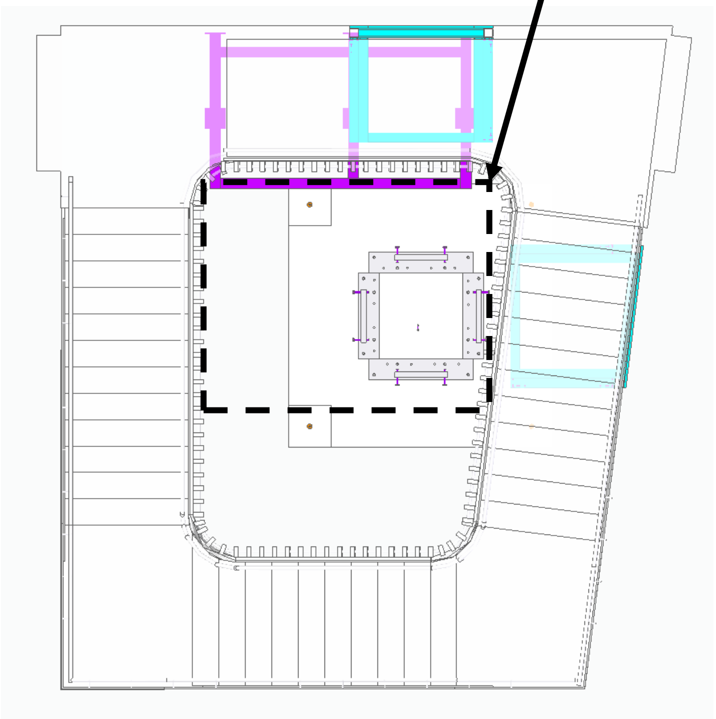
Screws to fix adjusted position



Installation process

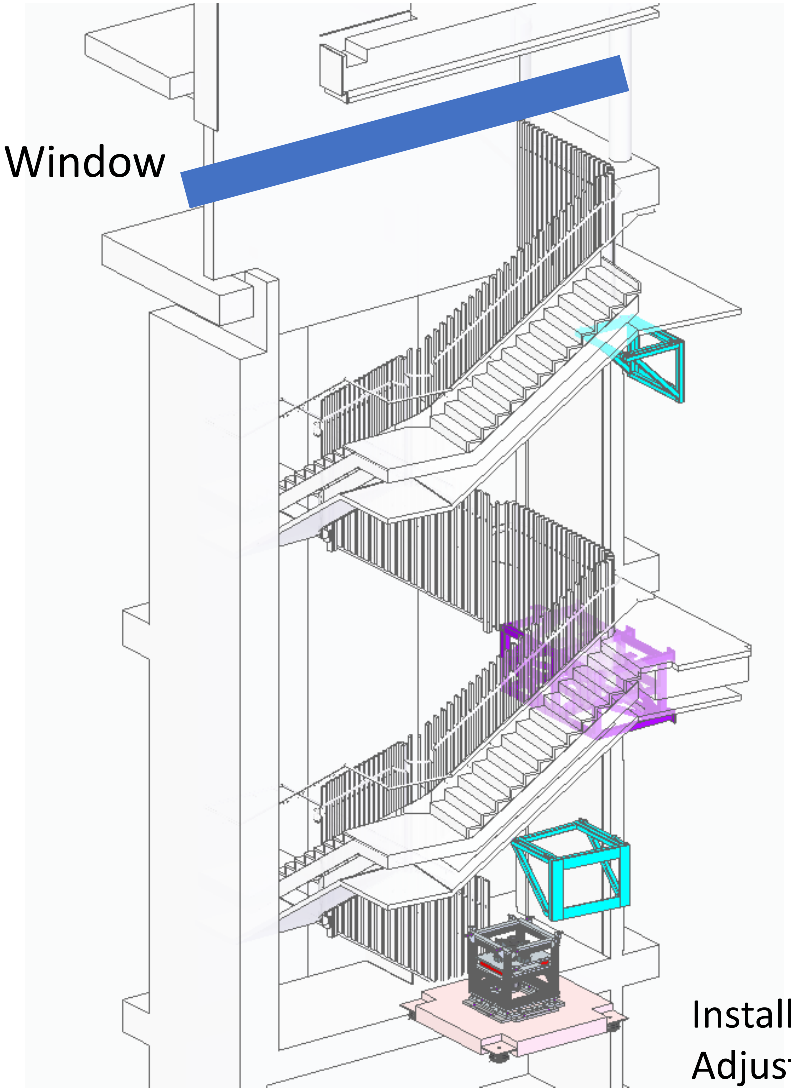


Side support frames are 2-part installed to not block the space available in the stairwell during craning

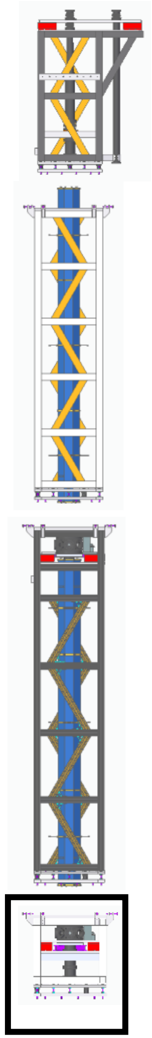


Install foundation, partial support structures and side arm platform frame

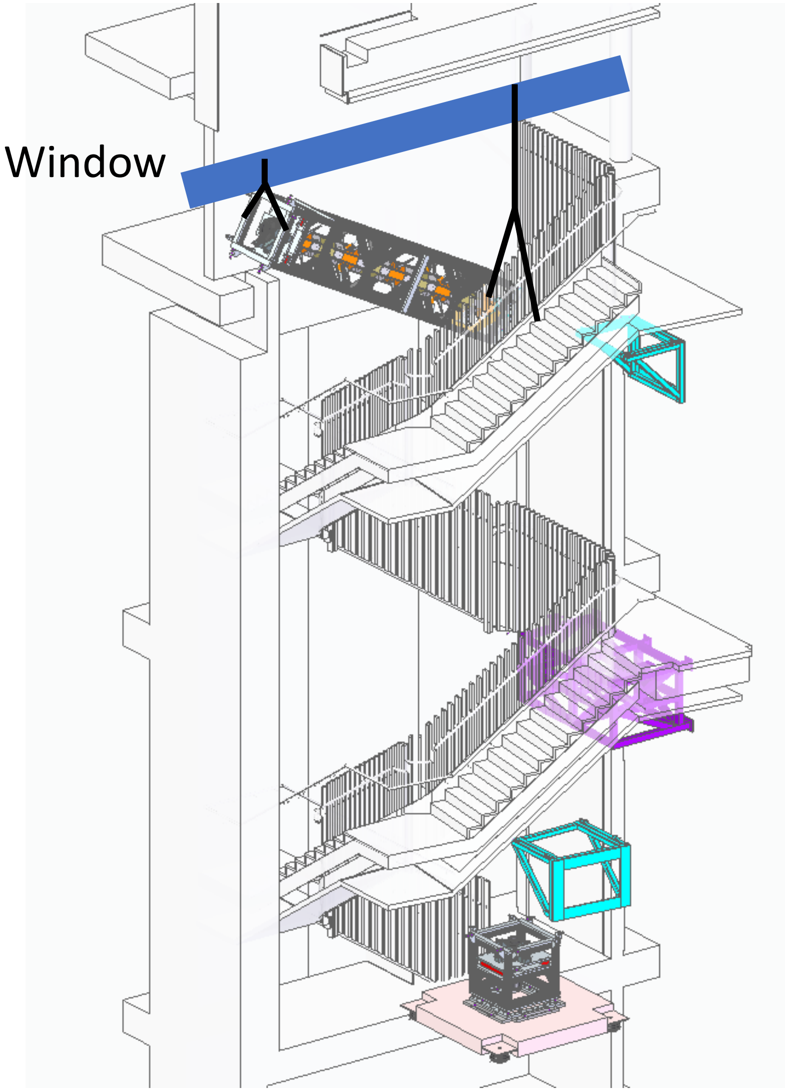
Installation process



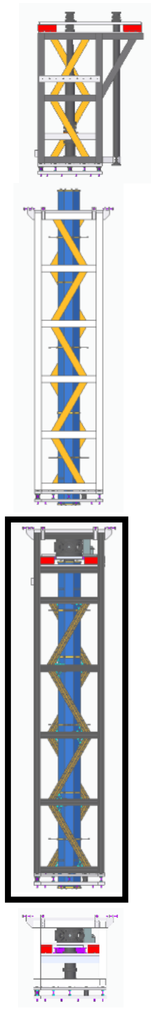
Install base module (possibly through elevator),
Adjust levelling of module



Installation process



Crane in lower main module



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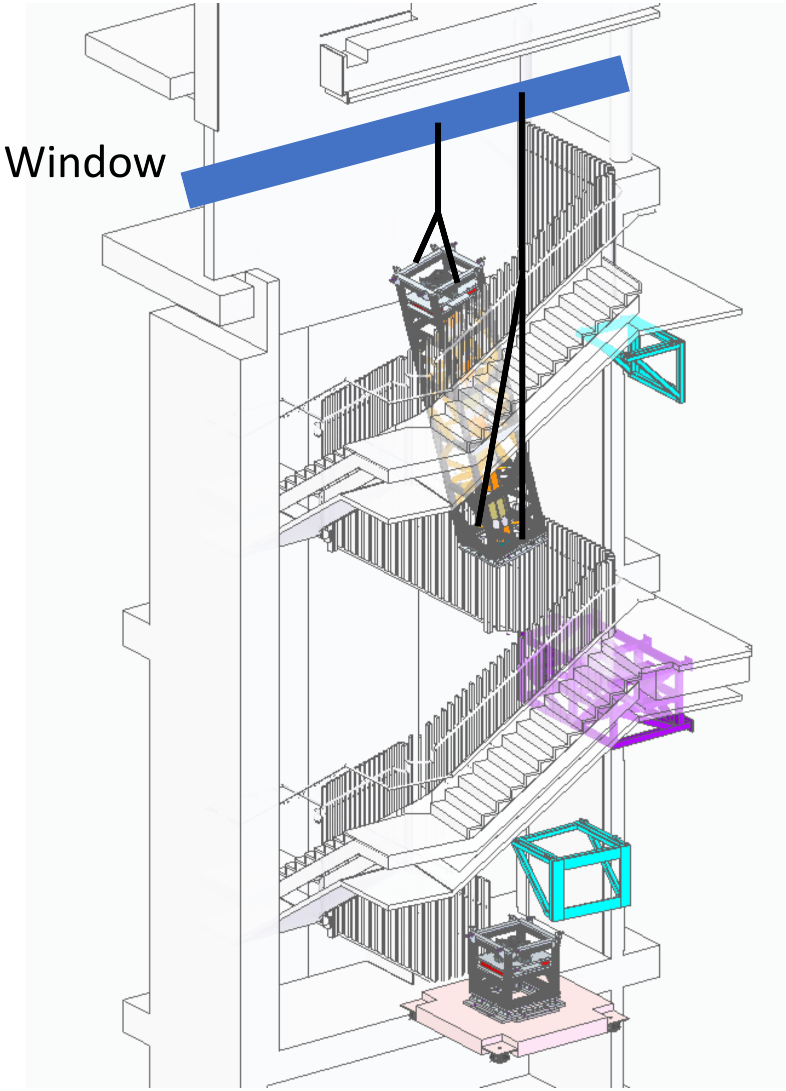

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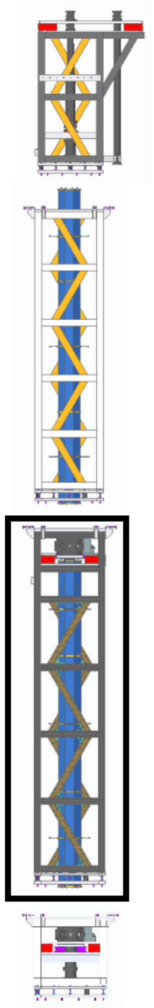

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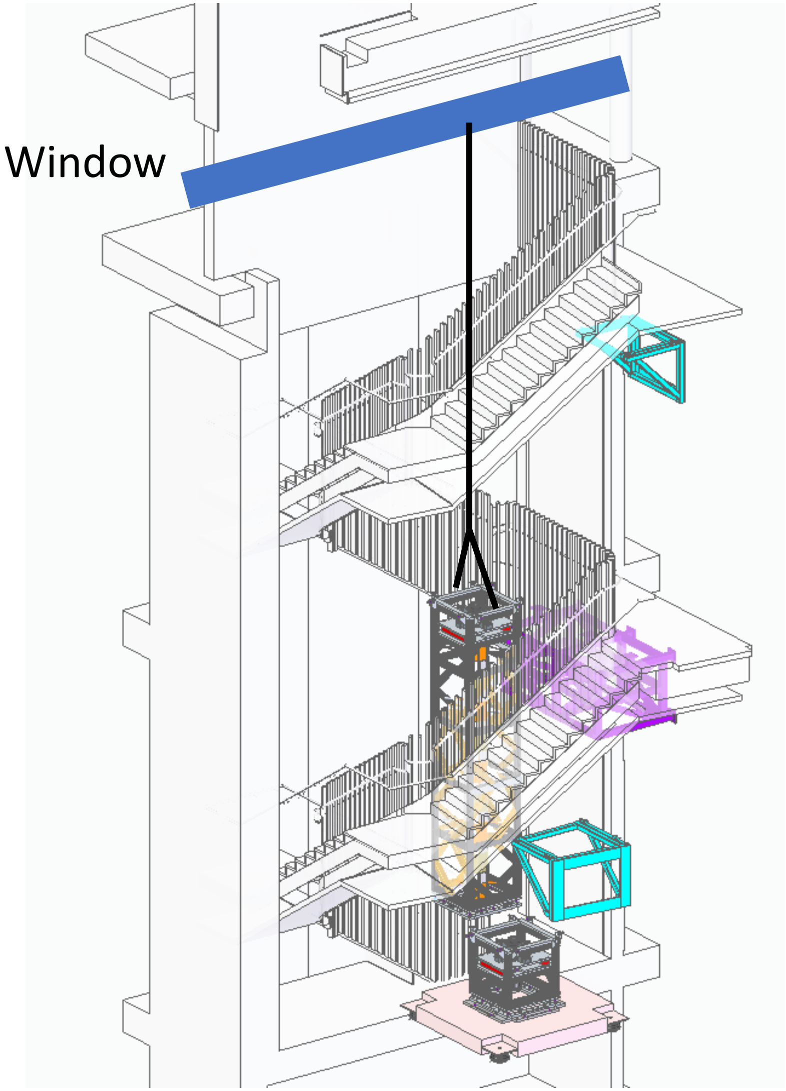
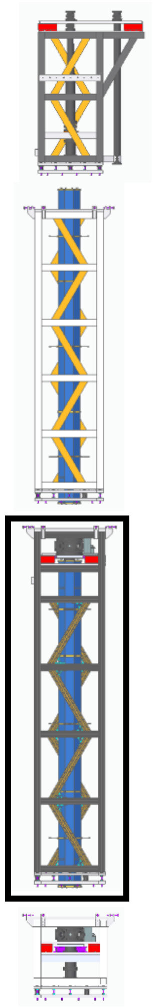


Crane in lower main module,
Adjust lateral alignment of module



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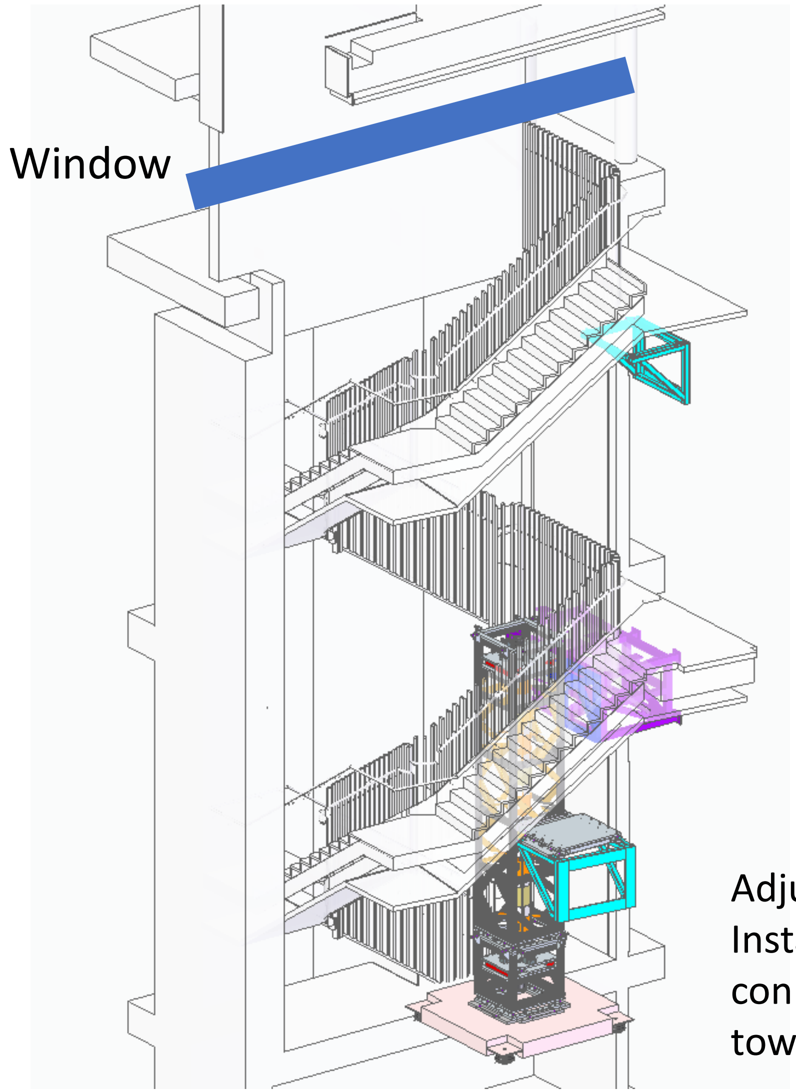
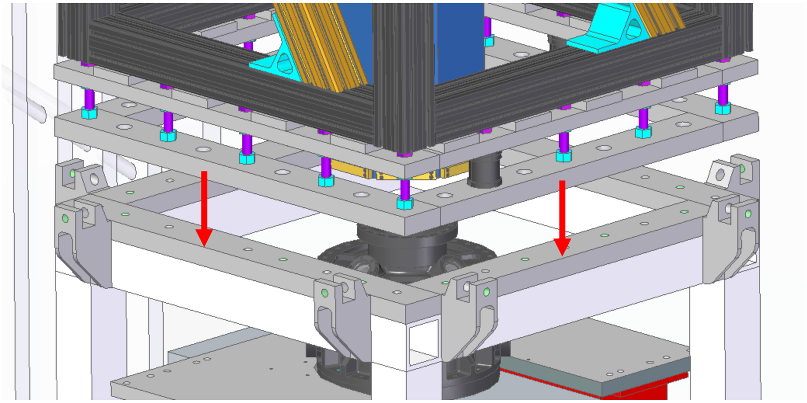
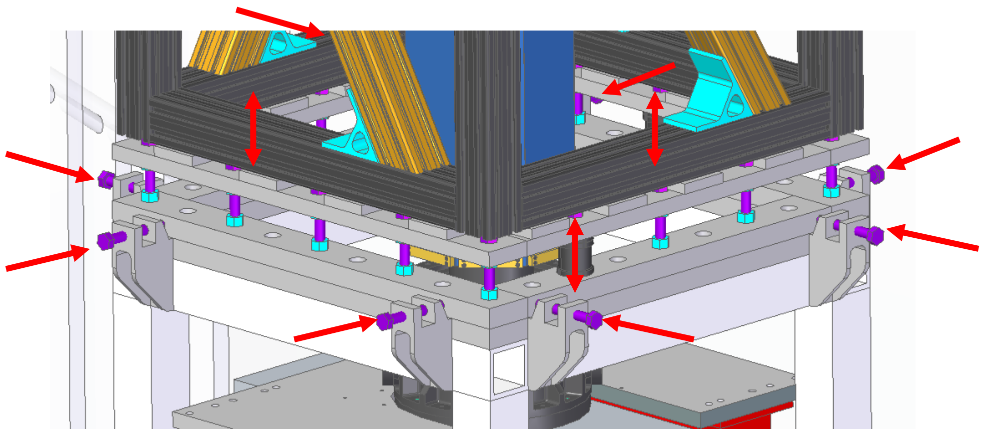


Adjust levelling of module,
Install side support frame by connecting existing base frame to tower

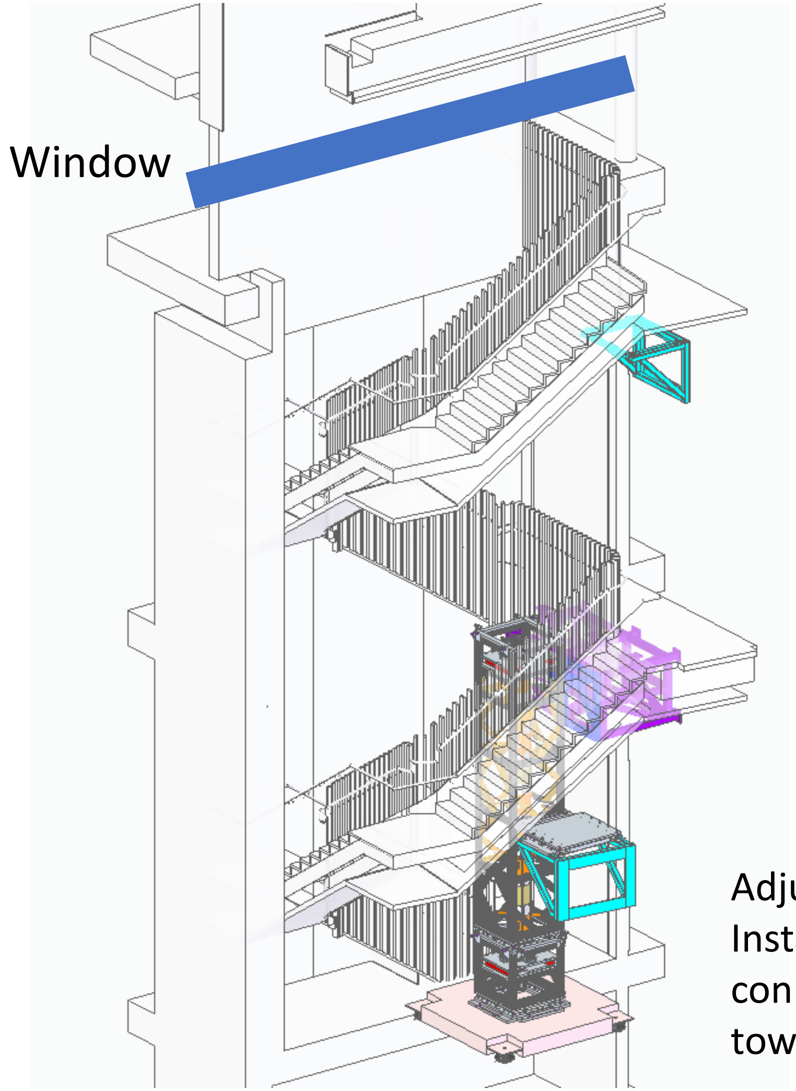


Brackets guide module to approximate position

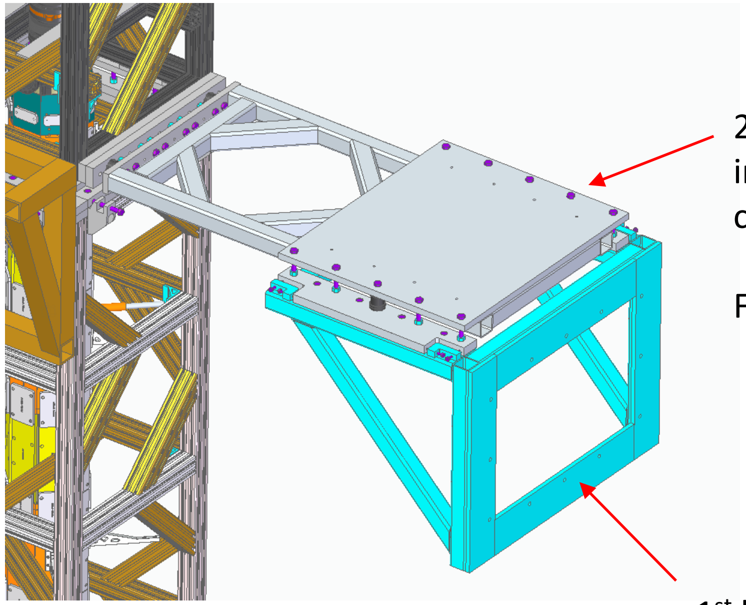


Position adjustment and level adjustment with screws and levelling adjusters

Installation process



Adjust levelling of module,
Install side support frame by connecting existing base frame to tower



2nd half of the side support frame installed onto base frame after corresponding tower module is installed

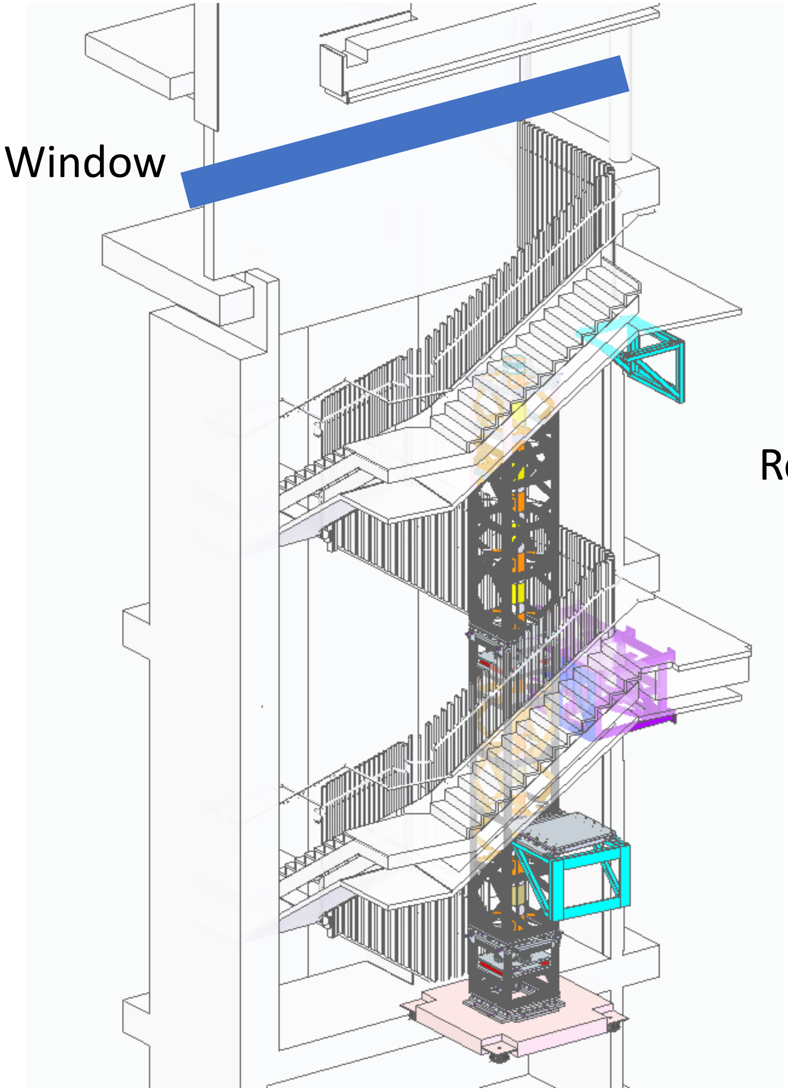
Fine position can be adjusted.

1st half of the side support frame installed onto Beecroft side walls before instrument installation

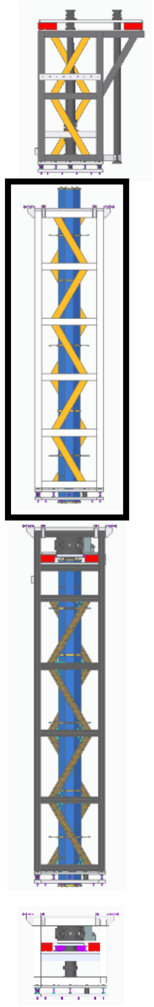
Coarse position fixed by concrete anchors

Temporary scaffolding may be required to access side support frame locations in the stairwell for installation

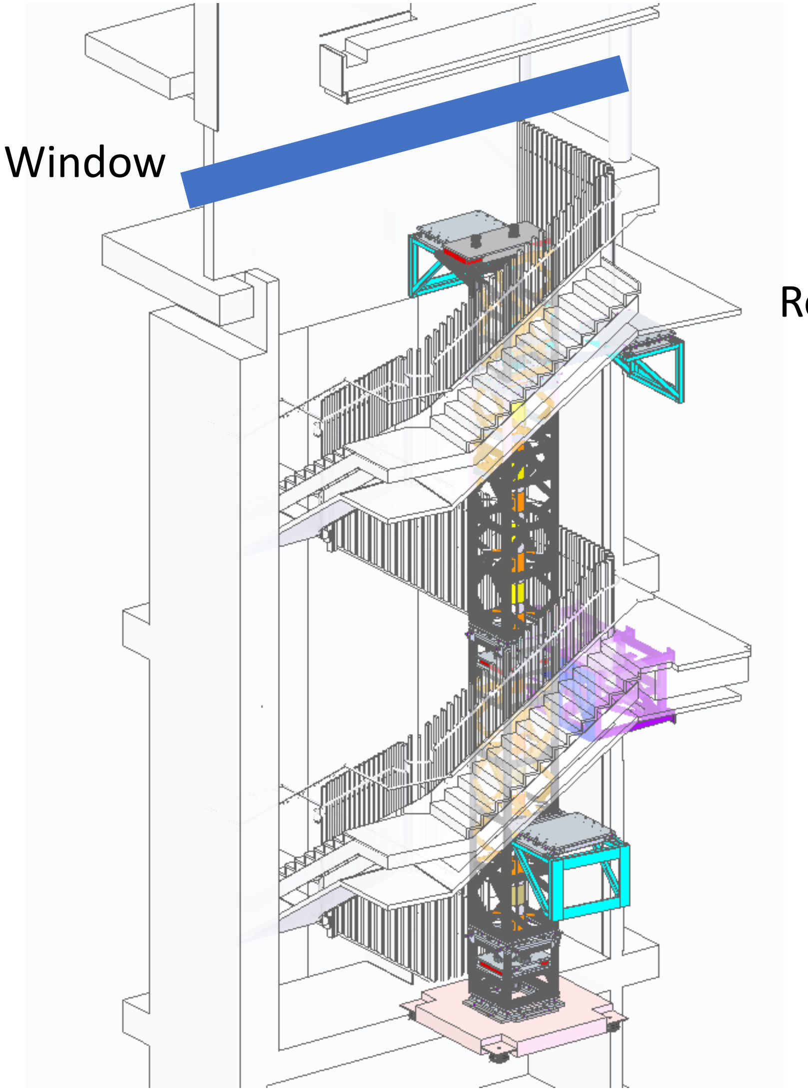
Installation process



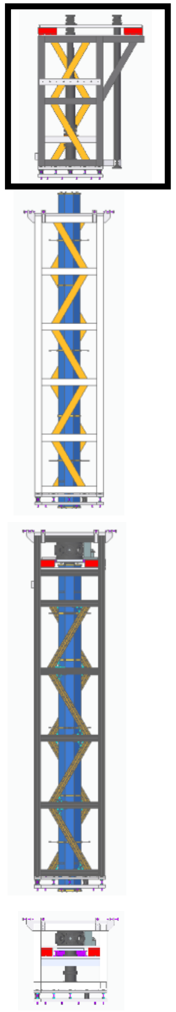
Repeat for upper main module



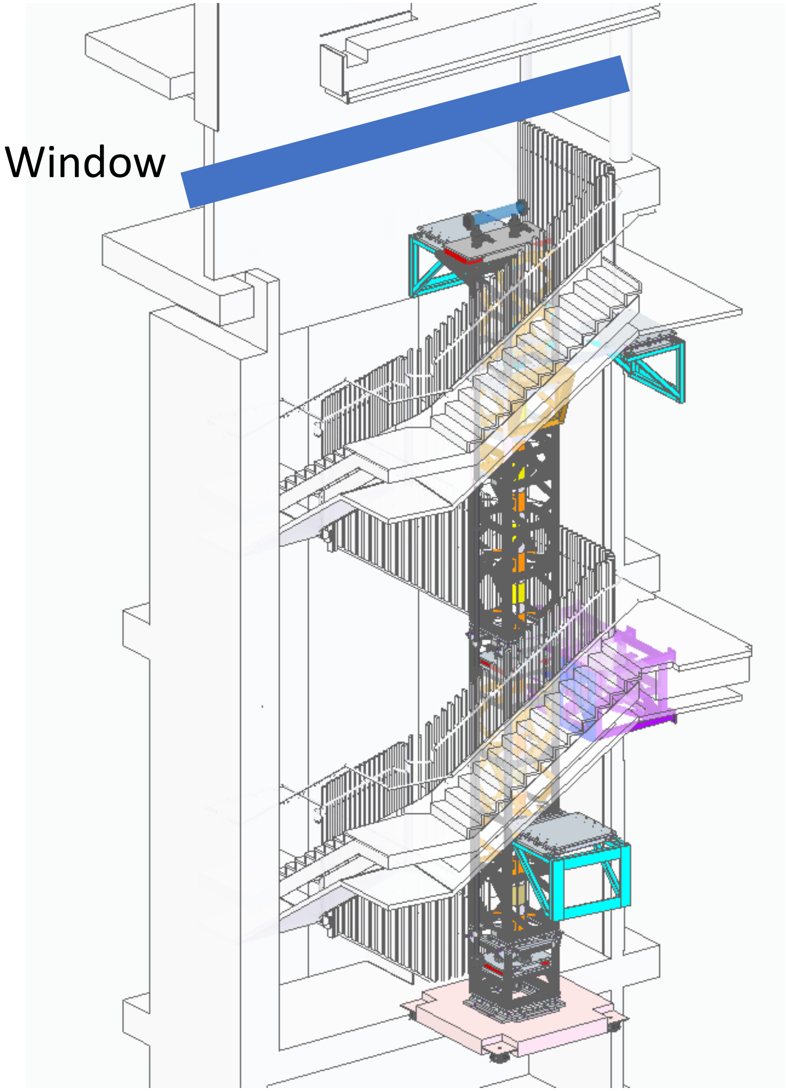
Installation process



Repeat for top module



Installation process



Install working platform on B1/F
Install remaining optics system components

- BTP
- BCP
- Ion pumps
- Optics around interconnect chambers
- Side arms

Challenges

- Craning system and lifting anchoring points for craning in long modules through the window
  - Module envelope and mass constraint
  - Current largest module mass 2000 – 2500 kg
- Accessing high points in the Beecroft stairwell within limited space
- Aligning and levelling frames and instrument section of each module
- Accessing optics around interconnect chambers for delicate instrument fine-tuning during commissioning
- Overall instrument mass and height constraint from the building
  - 10,000 kg allowable load on core concrete slab at B2/F, ~6000 kg for instrument and support tower + mass of inertial mass damper
  - ~15 m allowable height in stairwell, ~13 m instrument height + head room needed for crane system