Engineering for Diamond-II

Sarah Macdonell

Diamond-II: challenges and novel solutions for upgrading the national synchrotron light facility

Rutherford Appleton Laboratory

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Introduction

Engineering for Diamond-II

- Storage Ring
- Front Ends
- Injection
- Beamlines

What are we doing?

- Upgrading the storage ring, injector and Front Ends

- Requires removing almost all of the current machine and replacing with the Diamond-II machine

- New machine is based on a Double Triple Bend Achromat
  - Based on ESRF EBS upgrade
  - Reduces emittance – increasing brightness and coherent fraction
  - Introduces 24 ‘mid-straight’ sections for new insertion devices
  - Energy is increasing to 3.5GeV

- 3 New Flagship Beamlines

- Major & Minor Upgrades to existing Beamlines

Girder Requirements

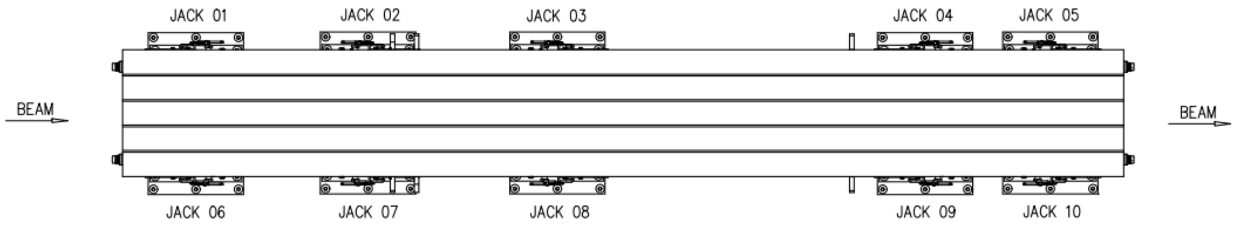
- Girder Vibration response
  - Requirement e-beam must not deviate in position by more than a 3% of the rms beam size in the straights up to 1 kHz with Fast Orbit Feed-Back (FOFB) ON
- Girder Alignment Requirements:
  - The Girder Global Position [µm] : ≤150
  - Dipole alignment/roll within girder [µm/µrad] : DQ 50/100
DL 100/100
  - Quad., Sext., Oct. alignment/roll within girder [µm/µrad]: 40/100

diamond

Prototype Girder

Motion Testing

- Feasibility of manually adjusting the wedge jacks as follows:
  1. Moves effected by 4 end jacks (1,5,6,10)
  2. Next 4 jacks engaged following move to increase system stiffness (2,4,7,9)
  1. All 8 jacks fine tuned
- All moves monitored and measured with:
  - 8 Linear encoders on underside of Girder
  - 12 Linear encoders (DTI) between magnets
  - 4 Inclinometers (2 Pitch & 2 Roll)
  - Full magnet survey with tracker before and after moves



DTI's mounted between magnets

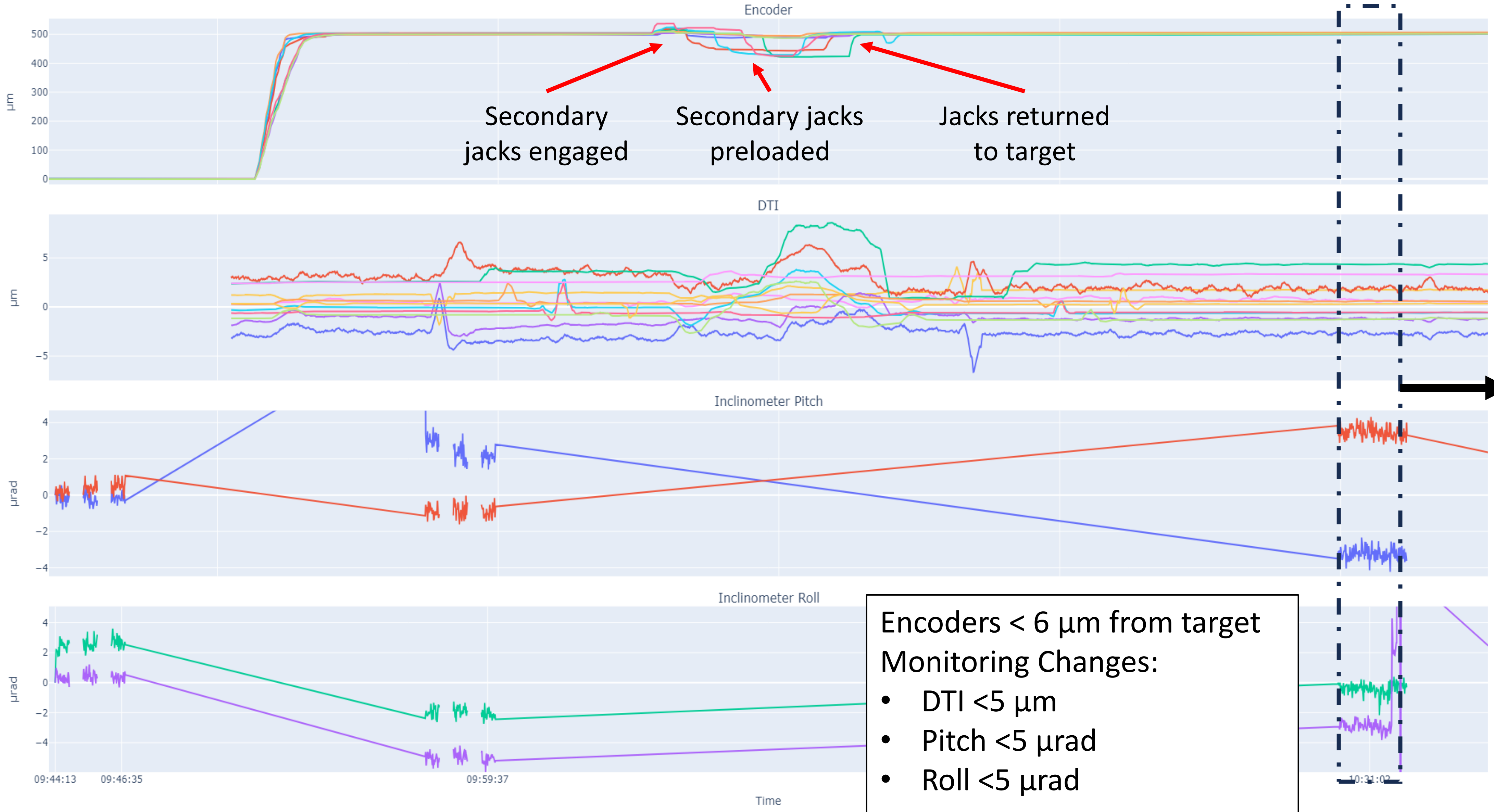
Requirements

Direction	Range
X	±4.6mm
Y	±5.2mm
Z	±4.55mm
χ	±1.5mrad*
η	±1.3mrad*
σ	±14.3mrad*

Direction	Accuracy
ΔX	±10μm
ΔY	±10μm
ΔZ	±10μm
Δχ	±10μrad
Δη	±10μrad
Δσ	±10μrad

* Derived from linear axes with zero linear offsets from nominal

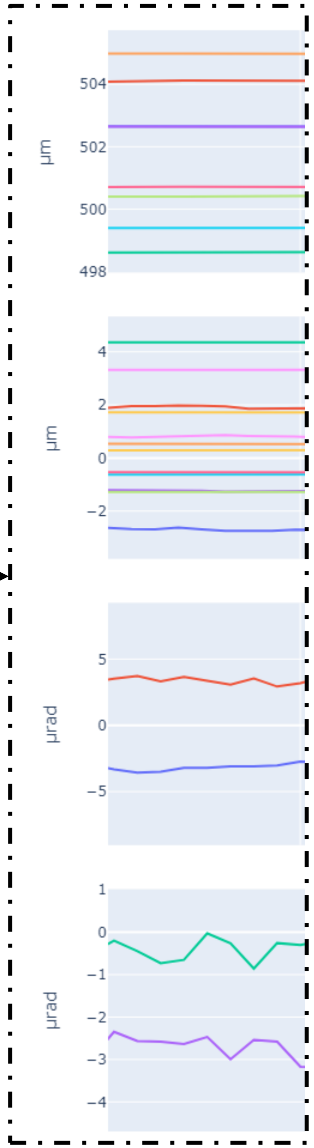
Prototype Girder – +0.5 mm Heave



Encoders < 6 µm from target

Monitoring Changes:

- DTI <5 µm
- Pitch <5 µrad
- Roll <5 µrad



Zoomed on Final Position

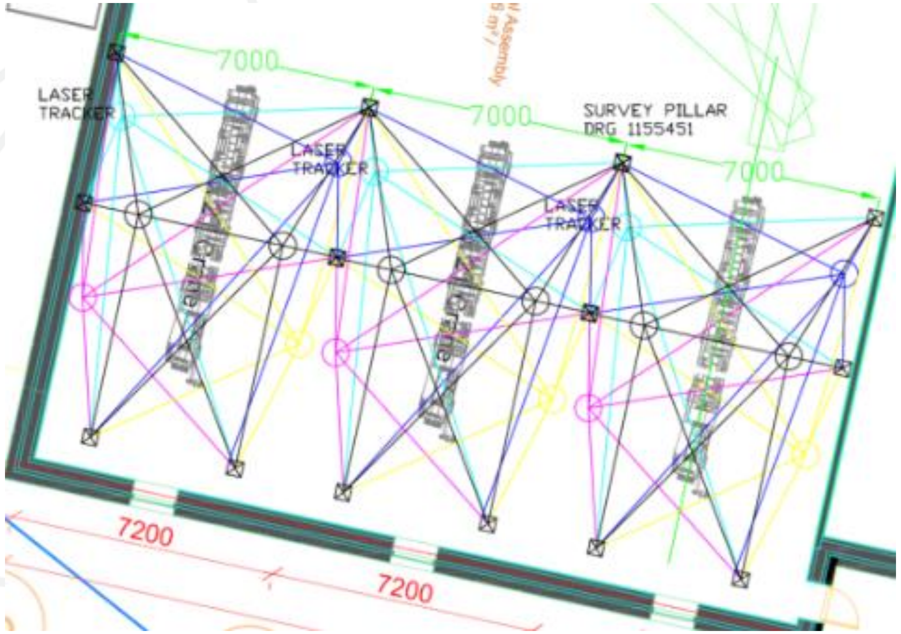
Prototype Girder Relative Movement

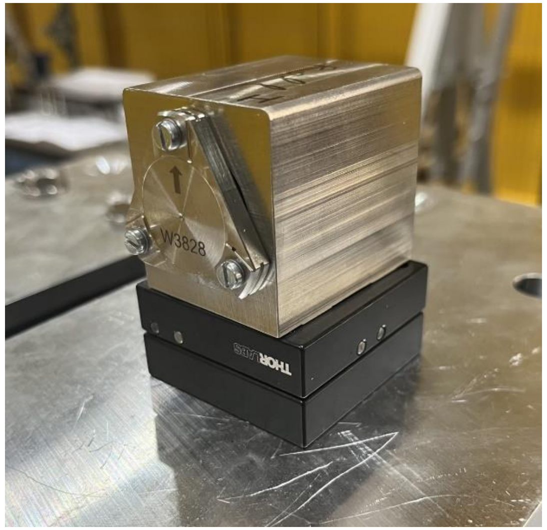
- Manual alignment of the girder with 4 jacks has been shown to be feasible for relative moves
  - Test heave, pitch and roll moves all within required accuracy from linear encoders, DTI and laser tracker average values
    - Further confirmation with multi tracker setup required
  - Inclinometer measurements for pitch and roll moves are outside of required accuracy at +/- 15 µrad
    - Not driven by manual actuation
  - Potentially significant cost saving with this change
  - Confirmed feasibility of manual alignment

- Also proven that the 4 inner jacks can be engaged and preloaded without significant impact on the girder alignment
  - Improving vibration stability as secondary supports and aligning with previously reported 8 jack configuration tested

Prototype Girder Positioning

- Simulated build – alignment – move – installation
  - Trial to simulate full assembly to installation sequence of girder carried out
  - All laser tracker measurements within measurement uncertainty from build to installation states
    - Laser tracker average difference between any two magnets 13 μm, max 44 μm
    - Laser tracker average difference between any adjacent magnets 6 μm , max 27 μm
  - At the limit of single shot laser tracker measurement uncertainty
  - Completed trials with multiple tracker setups and bundle adjustment required to confirm the above to required uncertainty

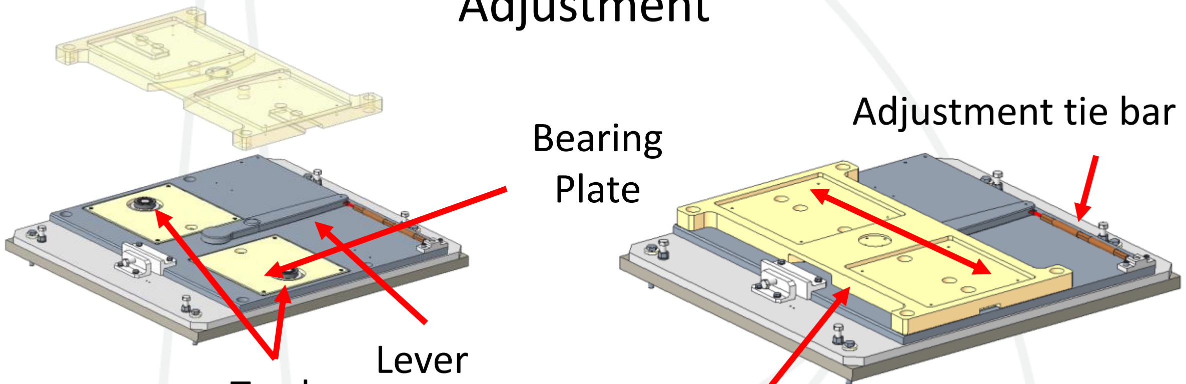


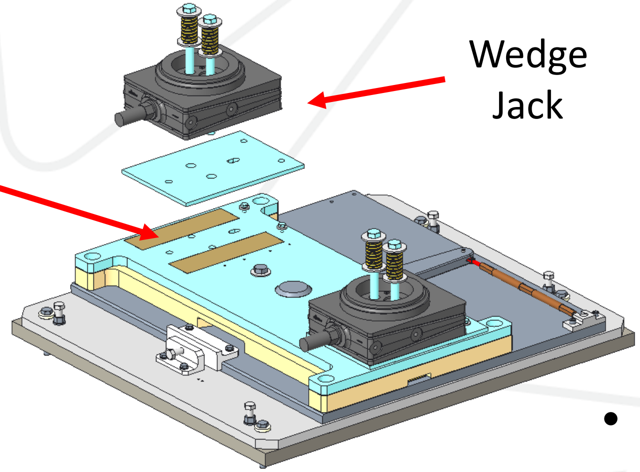


Prototype Girder Developments

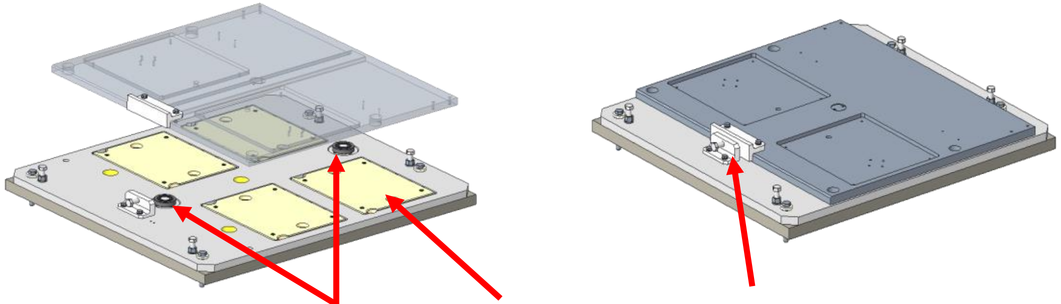
Updated prototype floor plate design completion to resolve issues with current design

Lateral & Yaw Adjustment

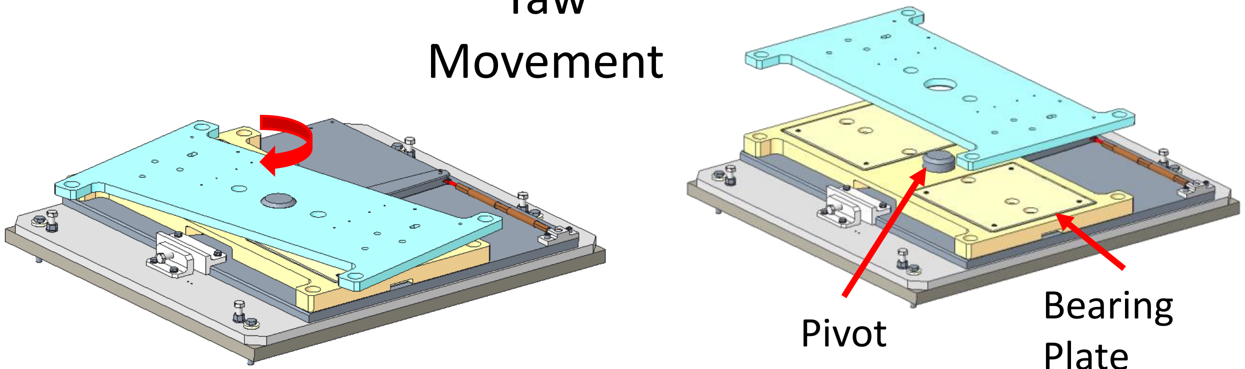




Surge Adjustment



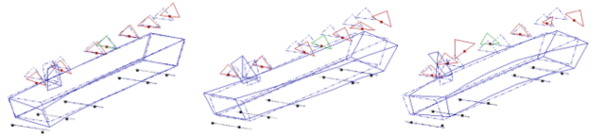
Yaw Movement



- Control of all axis of motion without over constraint
- Assembly is identical for both girder ends

Girder Vibration

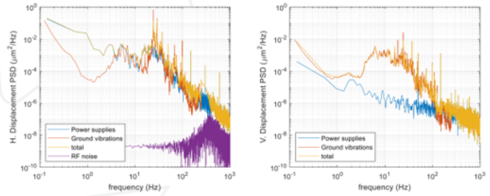
- Girder vibration response
  - Requirement e-beam must not deviate in position by more than a 3% of the rms beam size in the straights up to 1 kHz
    - Many contributing factors: magnet PSU noise, BPM noise, Girder vibration
    - Requirement is with FOFB ON
    - Passively the prototype girder + PSU = V 4.4%, H 2.2% of RMS beam size



Rigid roll 27 Hz — Torsion / yaw 34 Hz — Horizontal bending 60Hz

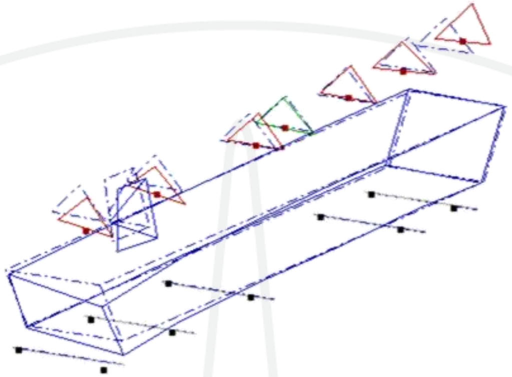
Configuration	Jacks Removed	Rocking Mode (Hz)				Torsion Mode (Hz)				Horizontal Bending Mode (Hz)		
		FEA	EMA			FEA	EMA			FEA	EMA	
9	10 Wedge Jacks	28.5	26.6	-7%		36.7	34.3	-7%		60.3	60.2	0%
6	3 & 8	25.6	23.4	-9%		36.6	34.4	-6%		60.3	56.3	-7%
7	2 & 7	25.6	21.9	-17%		35.5	34.4	-3%		69.4	59.4	-17%
8	5 & 6	22.6	22.7	0%		28.3	31.3	10%		59.8	58.6	-2%

No FOFB



FOFB

Location	Plane	Target µm	FOFB off µm	FOFB on (average*) µm
Long Straight	Horizontal	<1.20	0.72	0.28
	Vertical	<0.23	0.26	0.22
Standard Straight	Horizontal	<0.97	0.66	0.18
	Vertical	<0.18	0.53	0.14
Mid Straight	Horizontal	<0.90	0.23	0.17
	Vertical	<0.14	0.19	0.10



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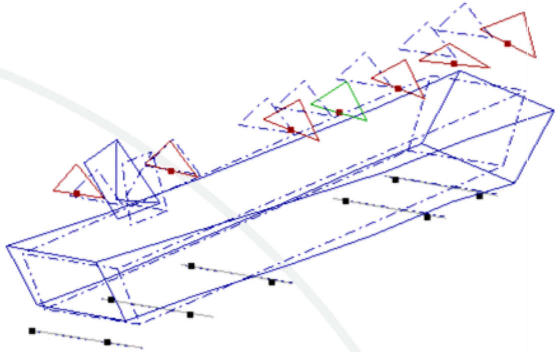
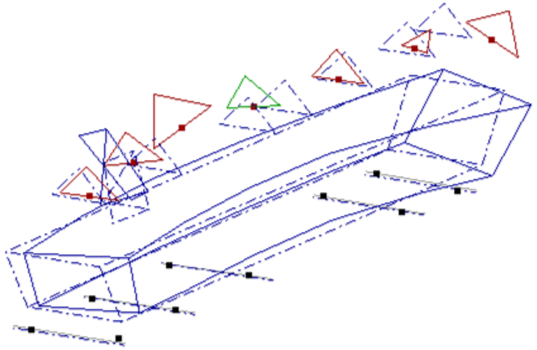


Torsion / yaw 34 Hz



Horizontal bending 60Hz

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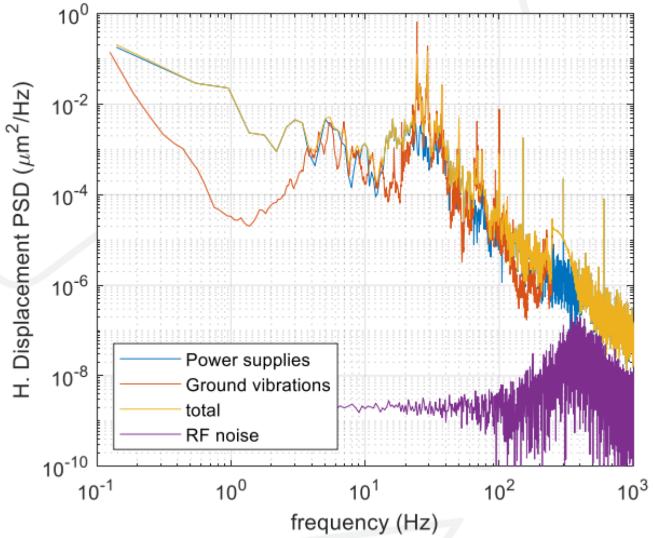

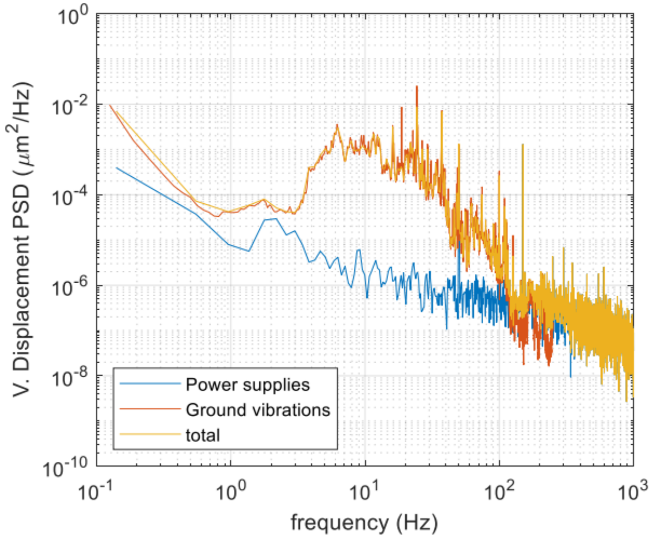

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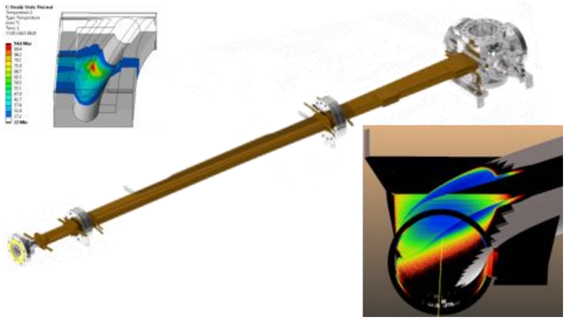
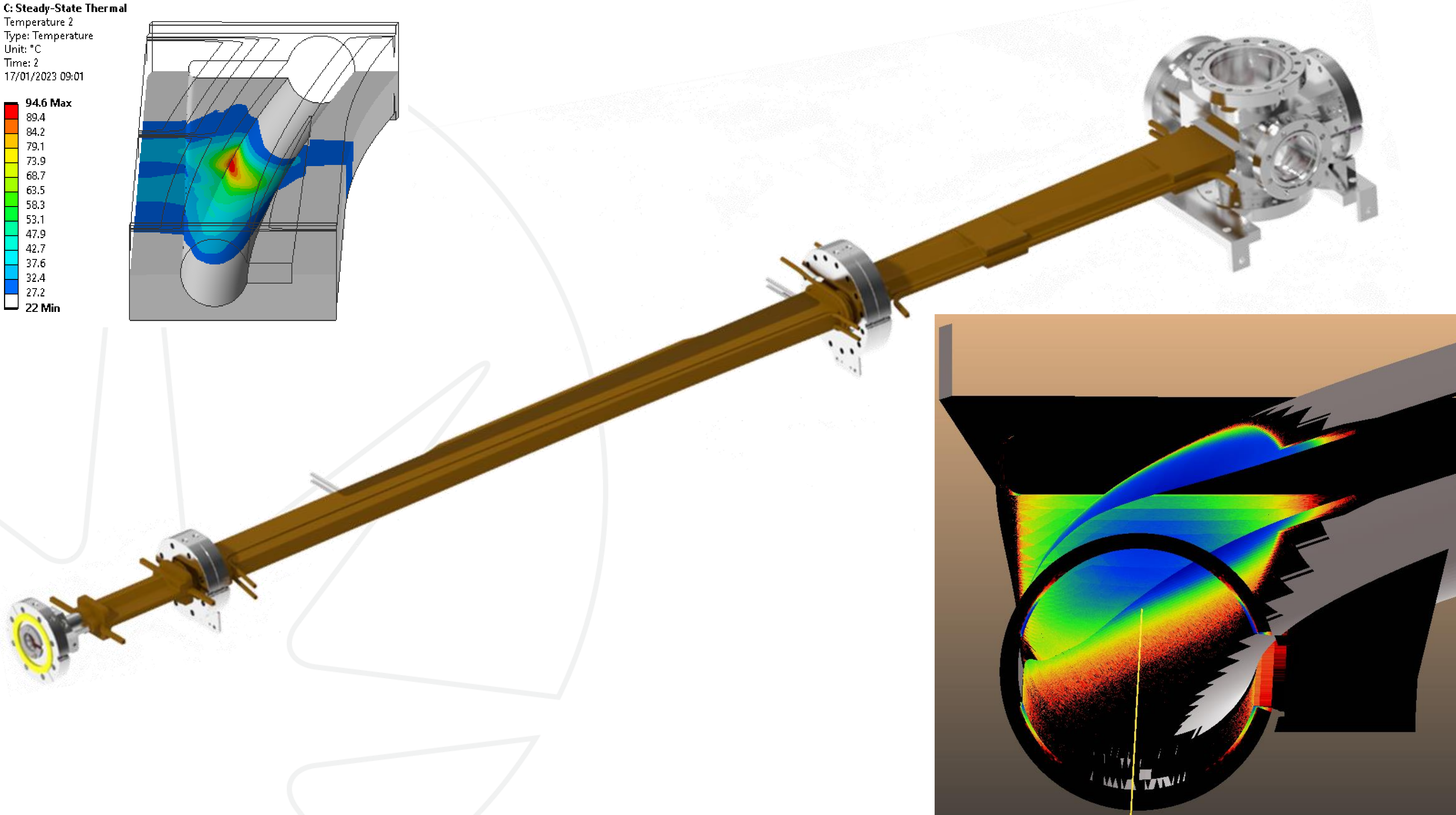
	Vertical	<0.14	0.19	0.10

Storage Ring - Other

- Key Developments
  - Vessel 2 Aluminium design changed to Copper
    - Resolving I05 power load issues
    - Improving Impedance
    - Reducing Cost*
  - Prototype Vessels
    - Most of the prototype vessels have been delivered now
  - DL magnet is undergoing magnetic measurements currently
  - Solutions for found for special B23 & B22 beam extractions and magnets

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Temperature 2
Type: Temperature
Unit: °C
Time: 2
17/01/2023 09:01
94.6 Max
89.4
84.2
79.1
73.9
68.7
63.5
58.3
53.1
47.9
42.7
37.6
32.4
27.2
22 Min

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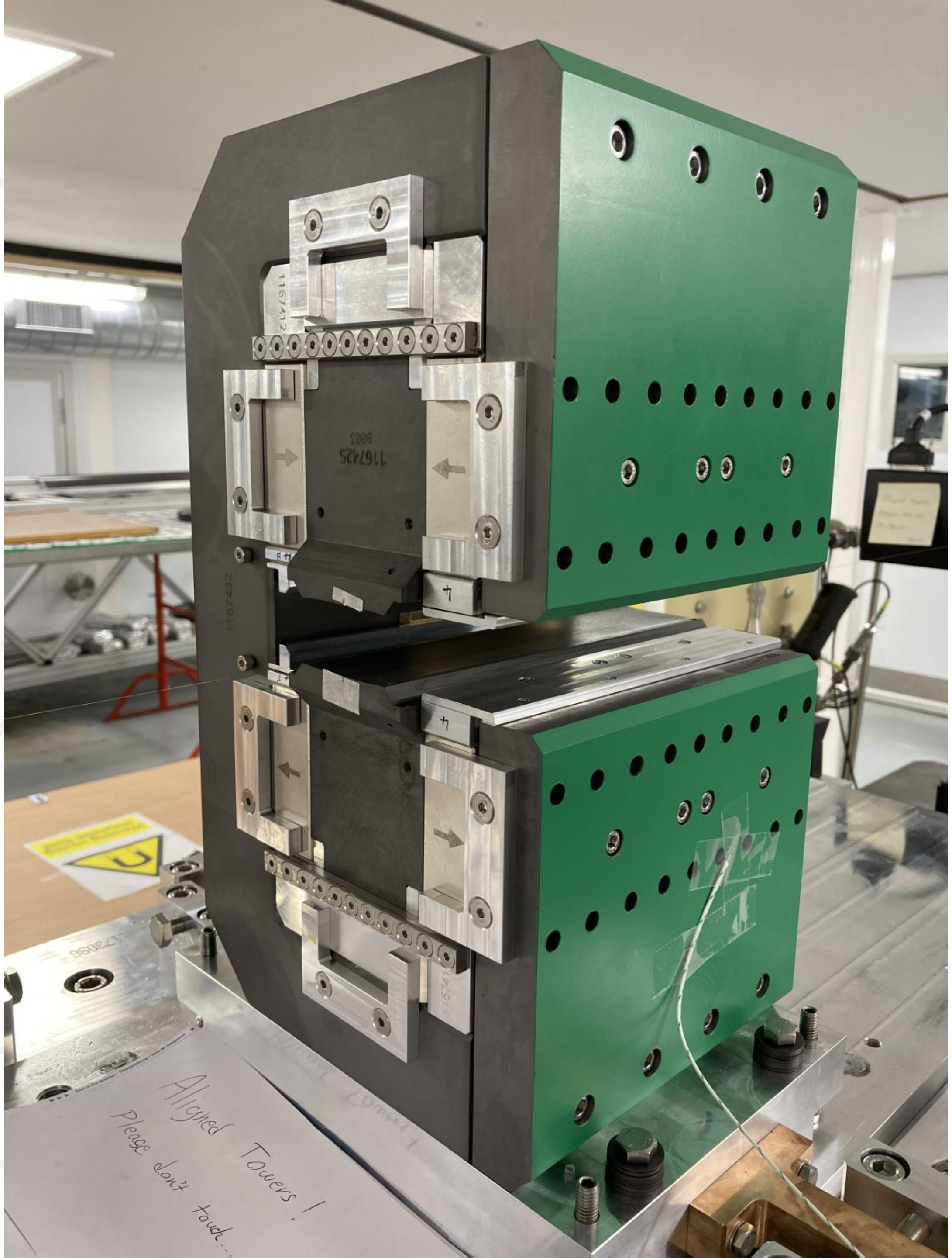

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Front Ends

Upgrade of 29 existing front ends

- 24 existing insertion device front end upgrade
  - *C1: New module zero*
  - *C2: Accommodating NC cavity*
  - *C3: Front end realignment*
  - *C4: Changes to wall penetration shielding*
  - *C5: Wall hole modification*
  - *C6: Change of photon exit aperture*
  - *C7: Upgrade of Absorbers*
  - *C8: Change of beam splitters*
  - *C9: Additional lead shielding*

Diamond-II TDR Table 2.5.4.2-1
Changes required to the existing insertion device front ends
n/a= not applicable

Front end	C1	C2	C3	C4	C5	C6	C7	C8	C9
I02	Yes	No	No	No	No	Yes	Yes		No
K02	Yes	No	Yes	Yes	No	Yes	No		Yes
I03	Yes	No	No	No	No	Yes	No		Yes
I04	Yes	No	Yes	No	No	Yes	No		Yes
I05	No	Yes	No	No	No	Yes		n/a	Yes
I06	No	Yes	No	No	No	Yes	No	n/a	Yes
I07	Yes	No	No	No	No	Yes	No	n/a	Yes
I08	Yes	No	No	No	No	Yes		n/a	Yes
I09-1 I09-2	Yes	No	Yes	No	No	Yes		Yes	Yes
I10	Yes	No	No	No	No	Yes		n/a	Yes
I11	Yes	No	No	No	No	Yes	No	n/a	Yes
K11	Yes	No	Yes	No	Yes			n/a	Yes
I12	Yes	No	No	No	No	No	No	n/a	Yes
I13-1 I13-2	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes
I14	Yes	No	No	No	No	Yes	No	n/a	Yes
I15	Yes	No	No	No	No	NA	No	Yes	Yes
I16	Yes	No	No	No	No	Yes	No	n/a	Yes
I18	Yes	No	No	No	No	Yes	No	n/a	Yes
I19	Yes	No	No	No	No	Yes	No	n/a	Yes
I20	No	Yes	No	No	No			n/a	Yes
I21	Yes	No	No	No	No	Yes	No	n/a	Yes
I22	Yes	No	No	No	No	Yes	No	n/a	Yes
I23	Yes	No	No	No	No	Yes		n/a	Yes
I24	Yes	No	No	No	No	Yes	No	n/a	Yes

Front Ends

- 5 existing bending magnet front end upgrade

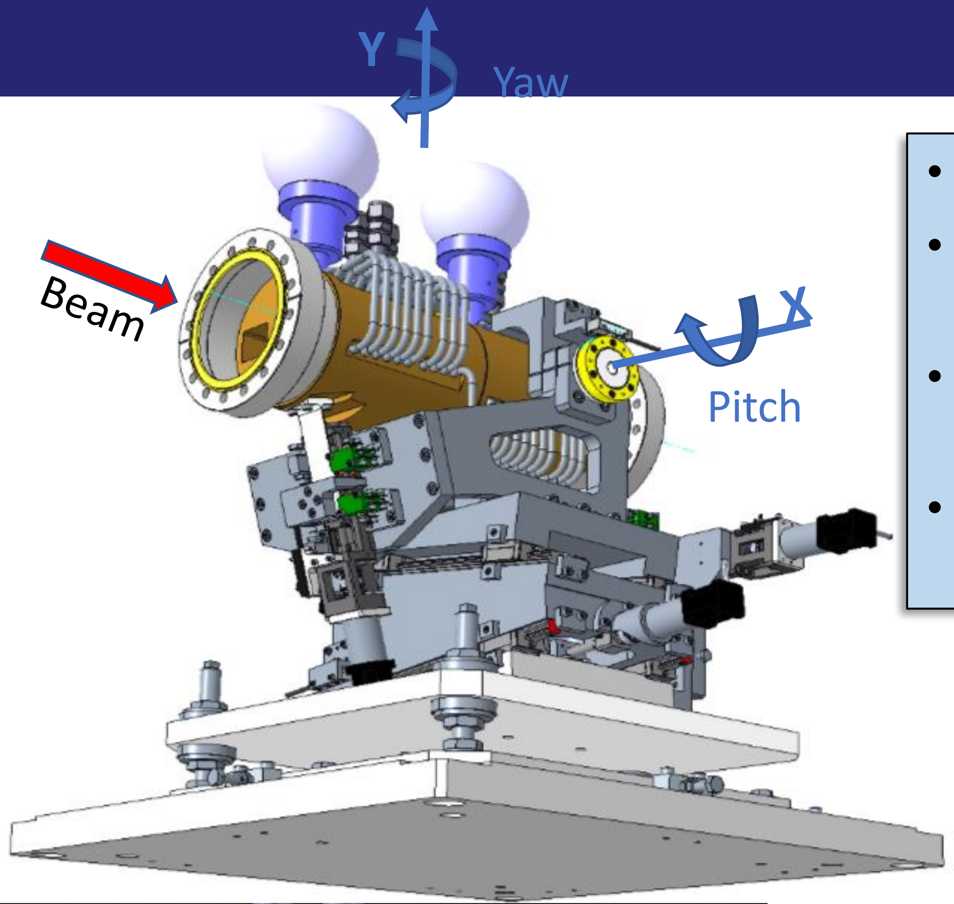
- New front end for K07.

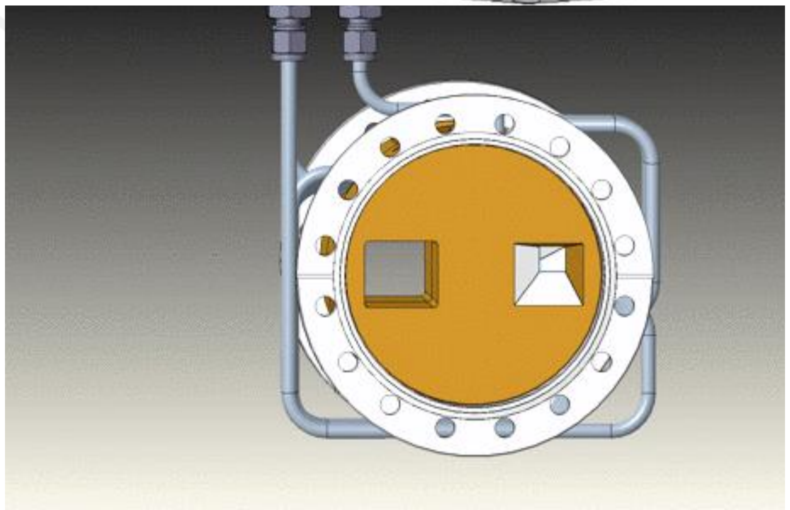
  K07 will have a ID branch and a BM branch. Two beams cross in the front end and beamline Mirror 1 is in the front end. Challenging front end design and challenging radiation management.

- New front end for B16, B18 and B21. Complications on radiation management due to the wall thickness of the existing optics hutch

- B24 - new upgrades to be confirmed. Change wall penetration shielding

Front Ends





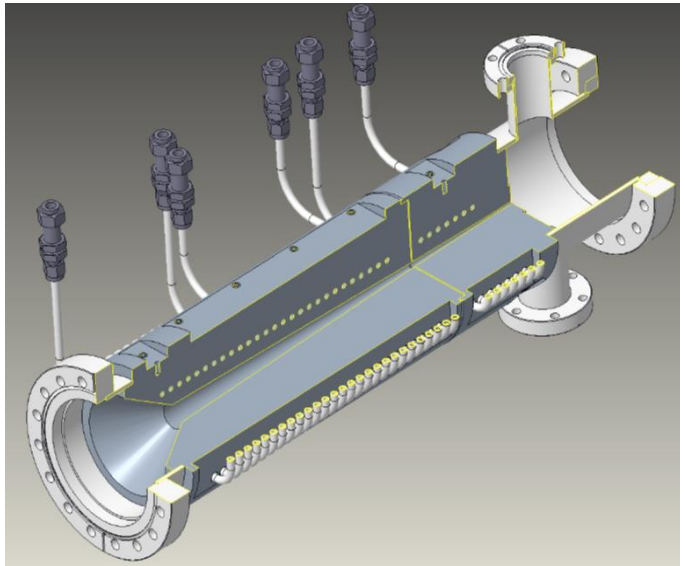
- Compact slits is required to solve the space shortage issue at the front end.
- The design has been developed based on a rotatable slits concept presented in MEDSI proceedings in 2014 by Oliver Schmidt from APS.
- The rotatable slits have all four beam defining blades integrated into one assembly module.
- Can vary the size of one branch of the beam while allowing the other branch of the beam to pass through unimpaired

Slits Specifications		
Max. Horizontal Aperture (mm)		5.2
Max. Vertical Aperture (mm)		4.65
Passing Beam Fan HxV* (mrad)		0.37 x 0.33
Horizontal Scan (mm)		±2.5
Vertical Scan (mm)		±2.5
Drive resolution (per full step)	Linear Motion (μm)	0.39
	Pitch Rotation (**arc seconds**)	0.49
	Yaw Rotation (**arc seconds**)	0.7

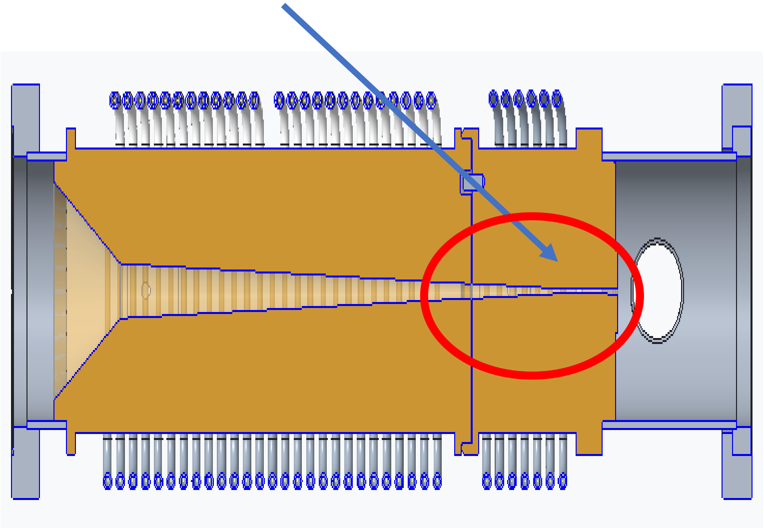
**Slits are placed at around 13 -14m from the source*

Prototype Custom Aperture

- One bottle neck of exiting front end modifications is the requirement of Ø 1mm pin hole Custom Aperture for several front ends in Diamond-II.
- To facilitate the fabrication, the copper body of the custom aperture is split.
- A prototype is made for the downstream copper body that has the Ø 1mm aperture.
- The aperture size is confirmed with a Go No-Go gauge. It is 0.98 to 1mm.
- Seeking precision measurements for the pin hole because of CMM limitations.

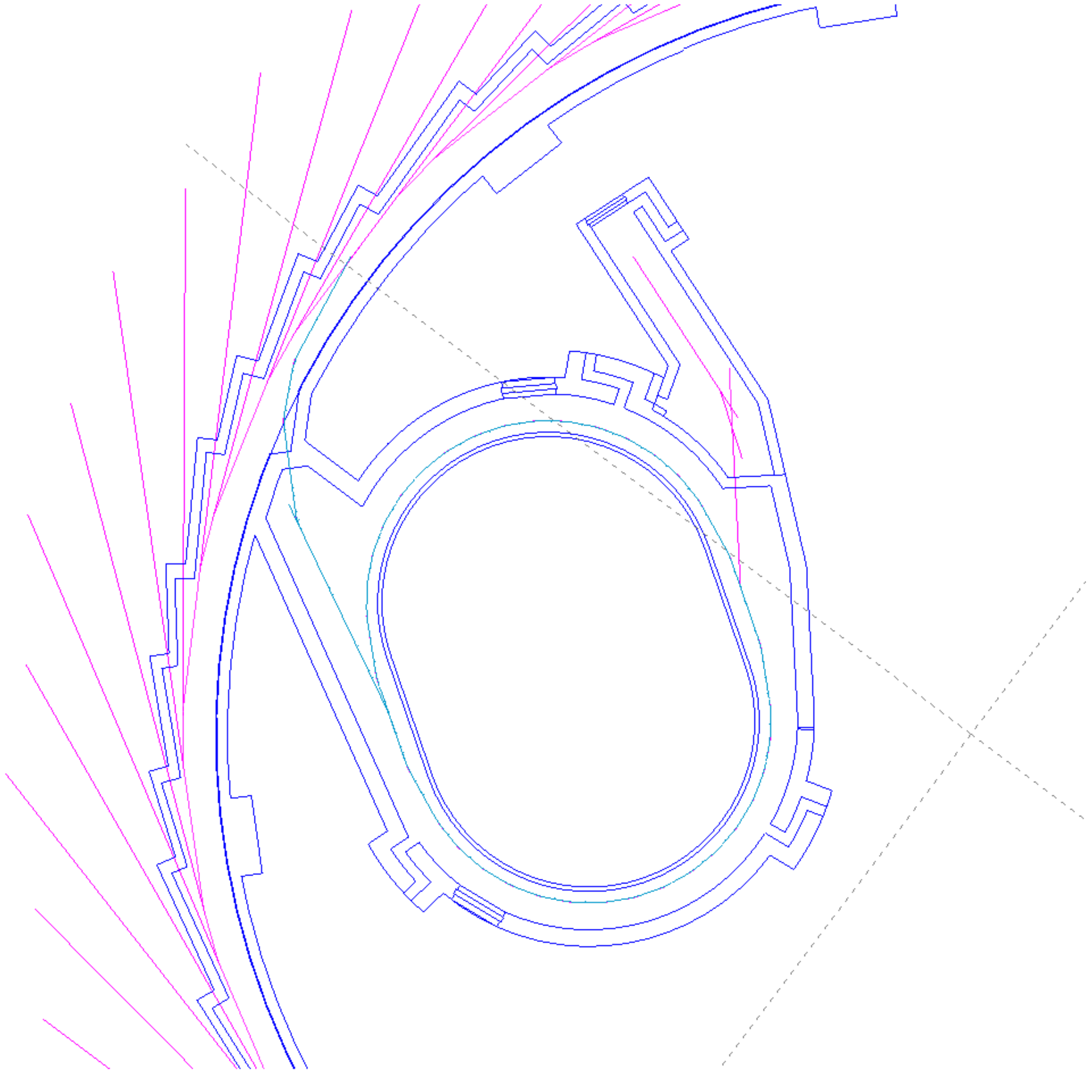


Go Ø 0.995 mm
No go Ø 1 mm



Injector

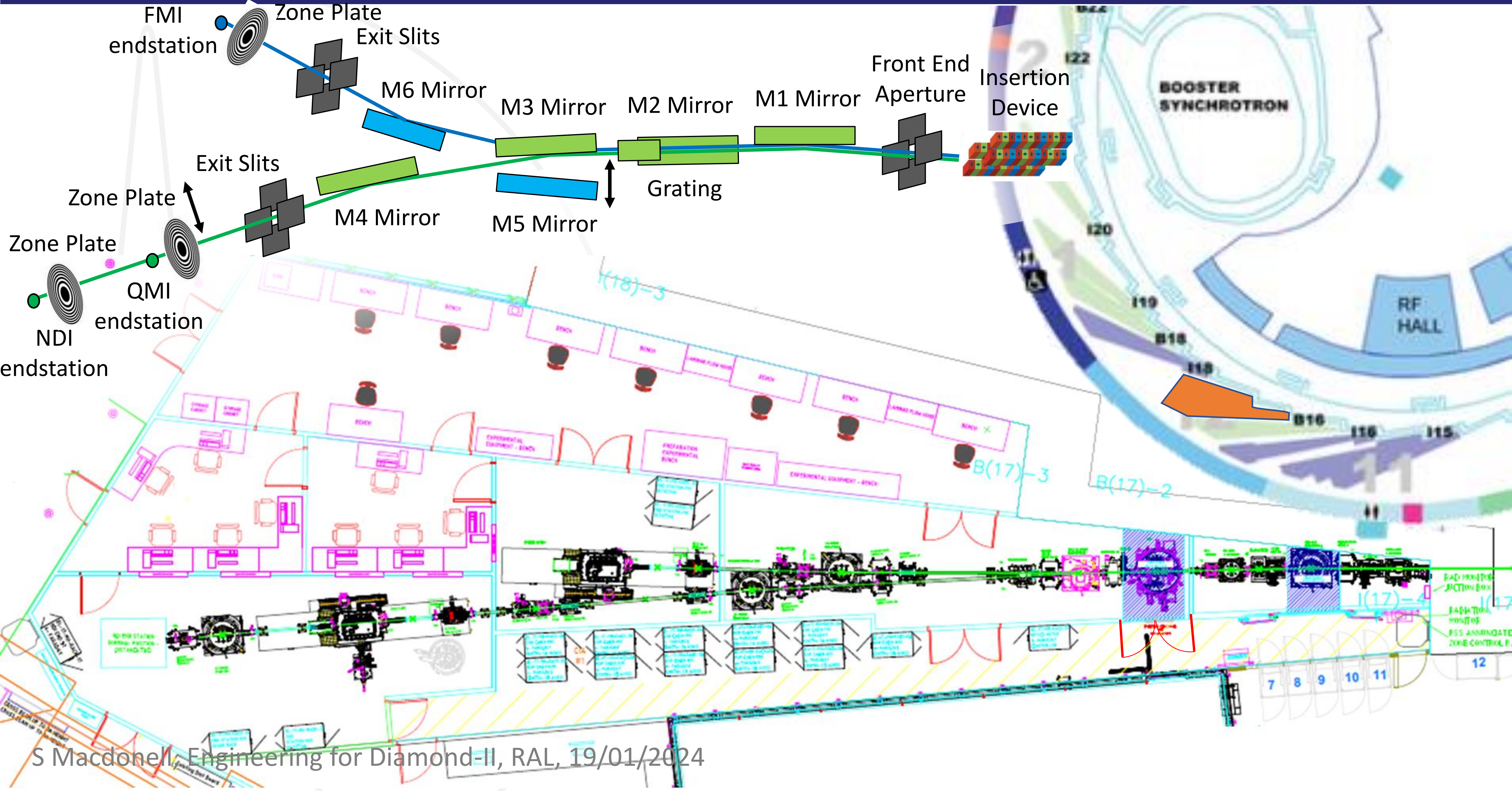
- New booster
- Modifications to transfer lines
- New injection into the SR



Diamond-II Beamline Upgrades

- **3 New Flagship beamlines in design**
  - SWIFT: Fast Operando Spectroscopy
  - K04: Ultra-high throughput for MX and XChem
  - CSXID: Coherent Soft X-Ray Imaging and Diffraction
- **4 Bending Magnet beamlines being upgraded to new sources which require major interventions with new optics and components, shielding etc**
  - B07: Versatile Soft X-ray (VerSoX) Beamline
  - B16: Test Beamline
  - B18: Core XAS
  - B21: High-throughput small-angle X-ray scattering
- **3 Bending Magnet beamlines requiring new optics in front end**
  - B22: Multimode InfraRed Imaging and Microspectroscopy
  - B23: Circular Dichroism
  - B24: 3D Correlative Cryo-Imaging
- **Most other beamlines requiring medium or small updates**
  - Optics, shielding, slits, diagnostics, collimators, windows etc

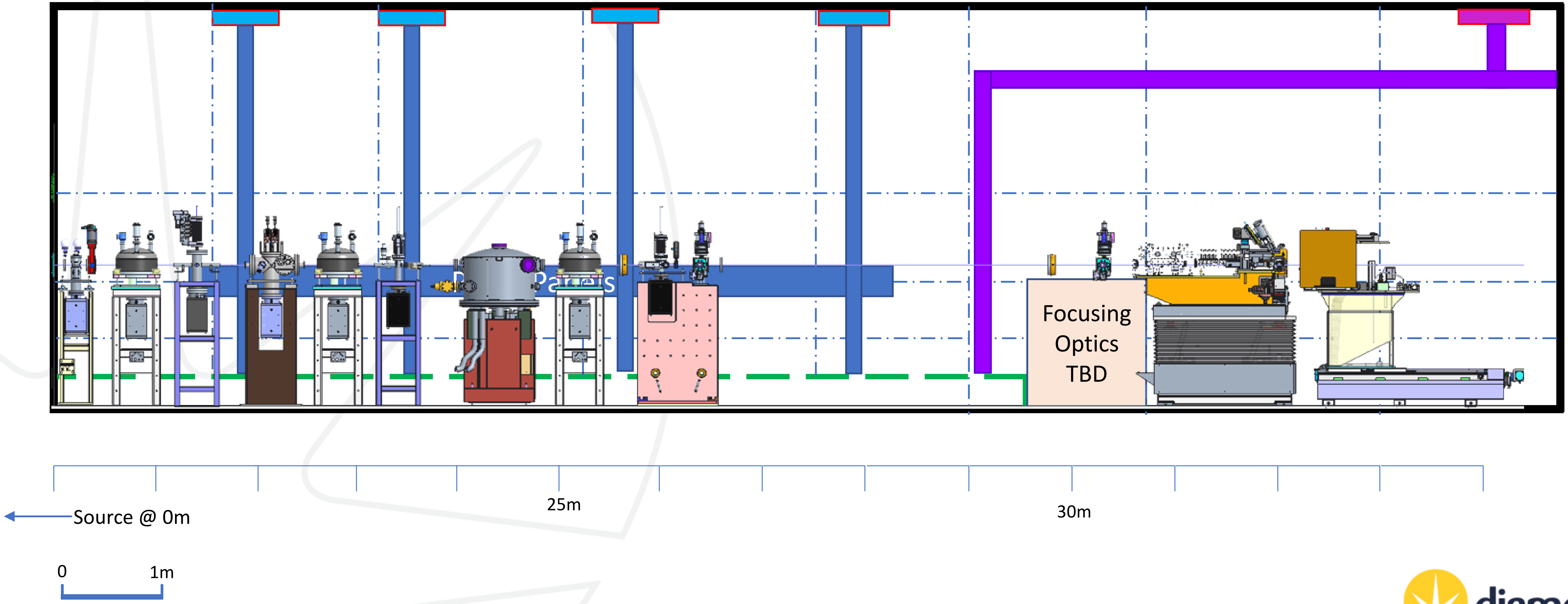
CSXID Flagship Beamline



K04 Flagship Beamline

Project Split into 4 Workstreams:

- Beam Delivery
- MX UHT End Station
- Automated X-Chem Lab
- Software



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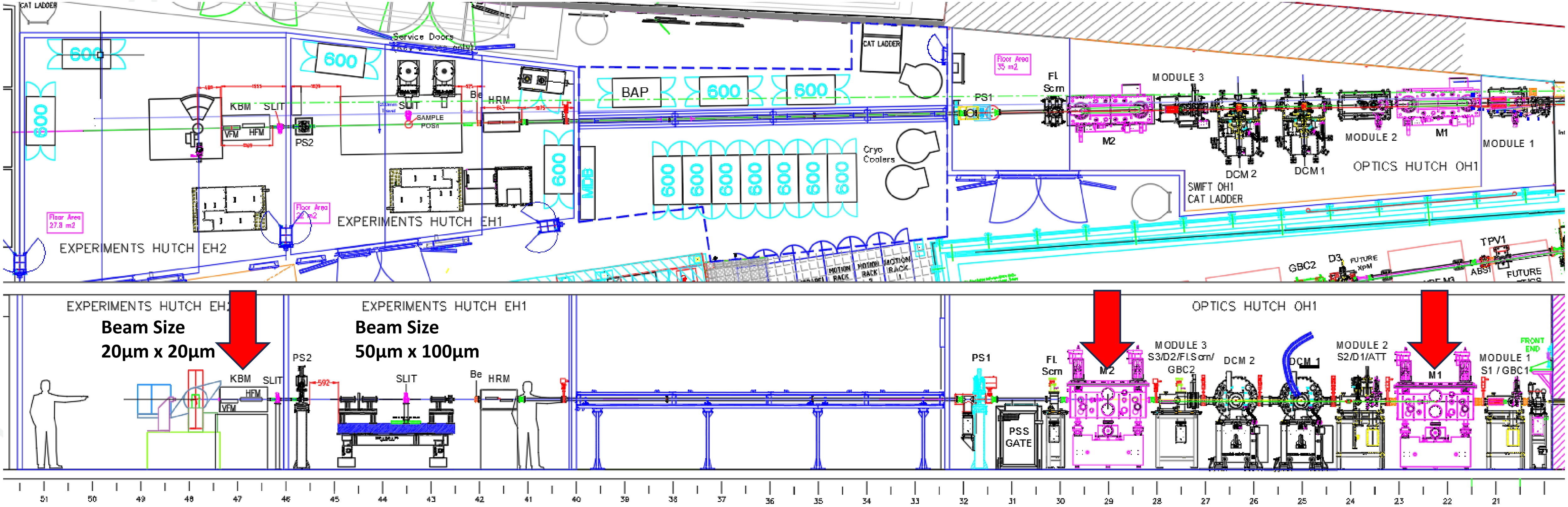
SWIFT Flagship Beamline



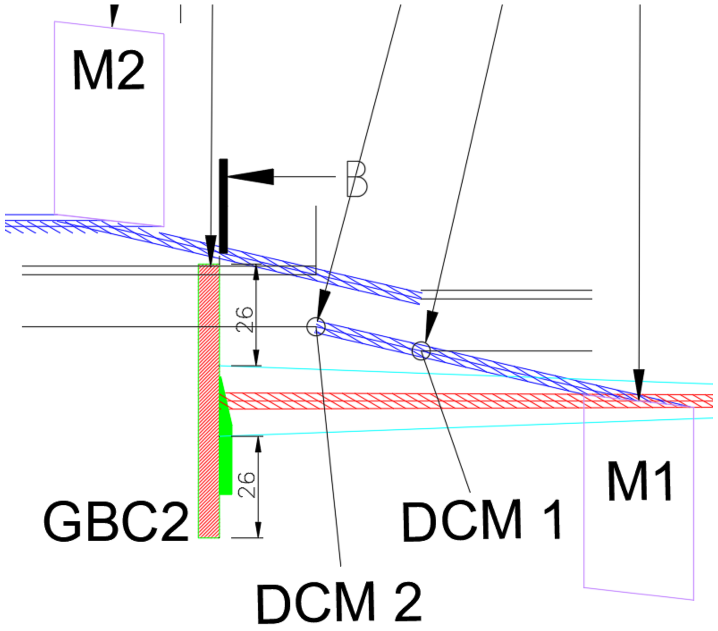
Beamline Components - largely DLS design except M1/M2, KBM & Slit bodies

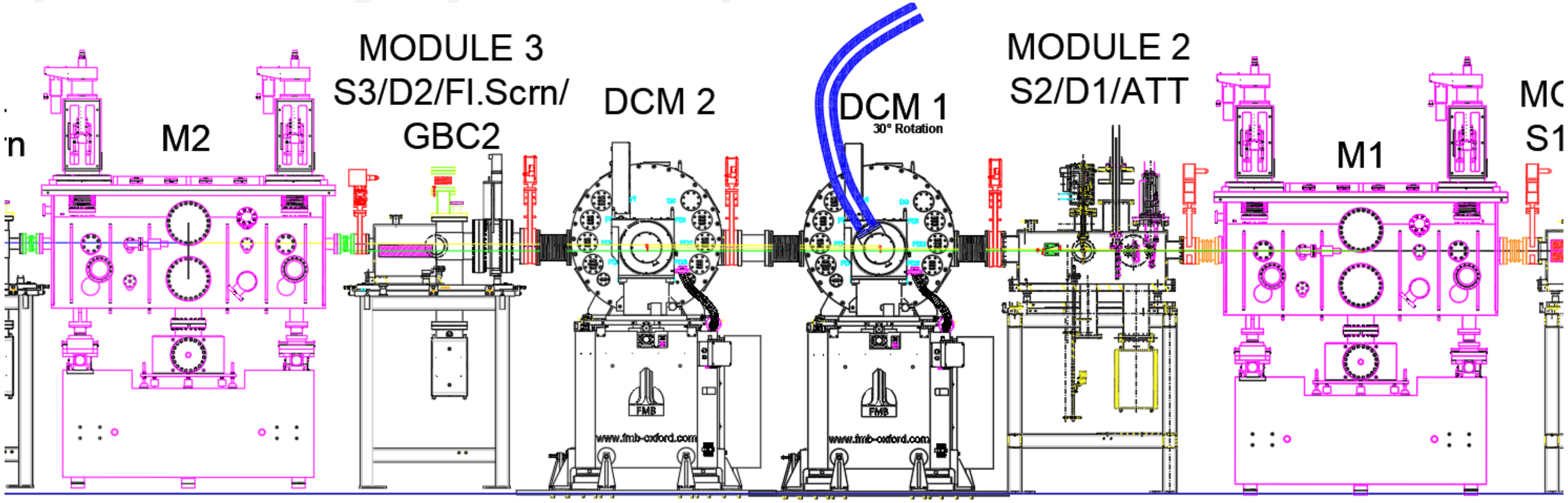
SWIFT Monochromators

Two Interchangeable LN2 Cooled Monochromators

- “Standard” Fixed Offset DCM
- QEXAFS DCM – Channel Cut
- Two Crystal Sets
- Energy range 4-36 keV
- 400W power

Both essentially deliver beam to the same point on M2





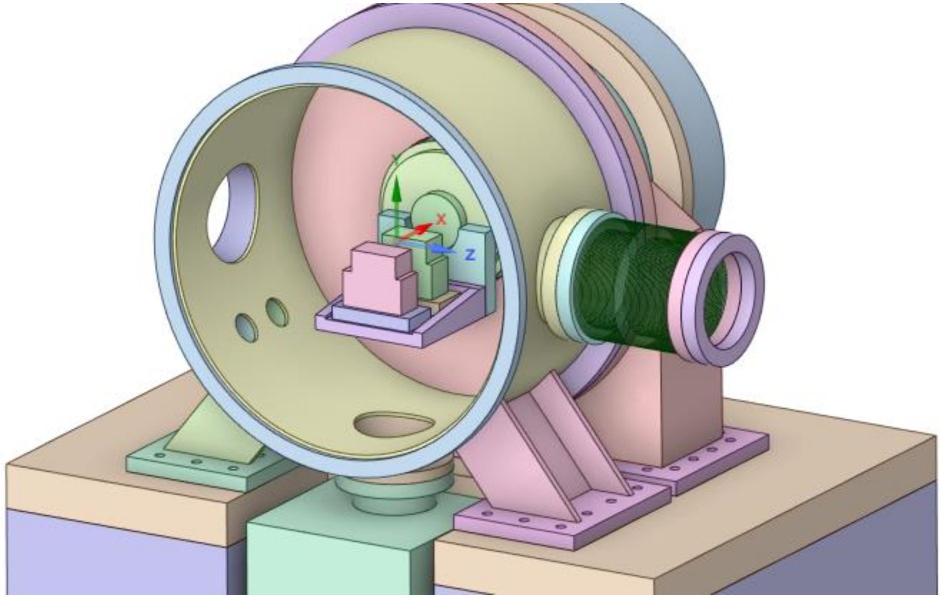
SWIFT Monochromators QEXAFS

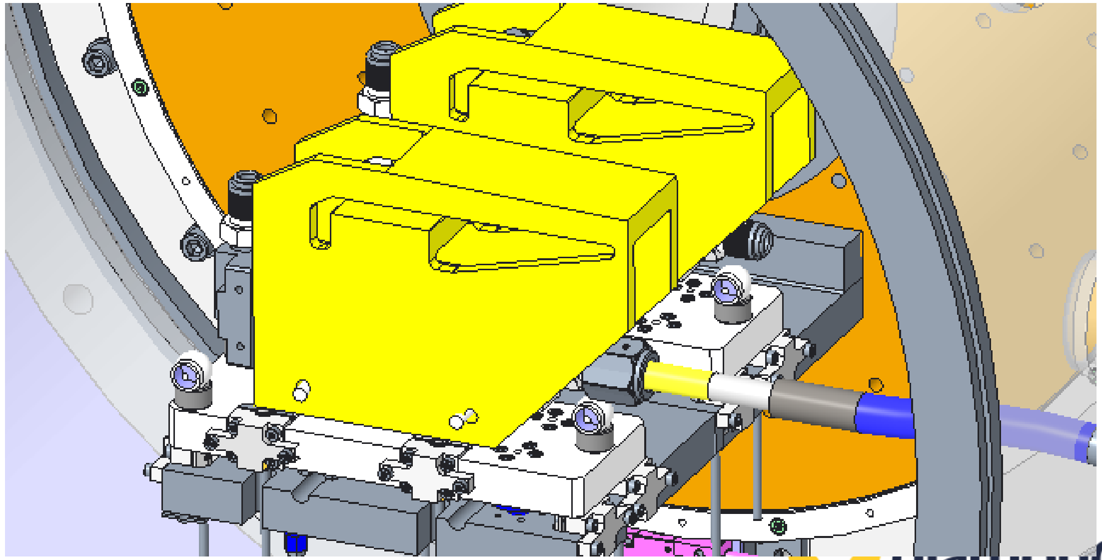
Scanning Range (Scans can last many hours)

- +/-0.25deg @ 25Hz (5deg Bragg Angle)
- +/-3deg @7Hz (30deg Bragg Angle)

Challenges

- Minimize Inertia
- Vibrations? (Impact on others!)
- Heat loads (400W) / Slope Errors (0.3µrad)
- Parallelism between channel cut crystal faces
- Cooling connections / leaks
- Loosening fixings / components





Acknowledgements

Entire Engineering Group

With particular mention of:

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Thanks for listening!