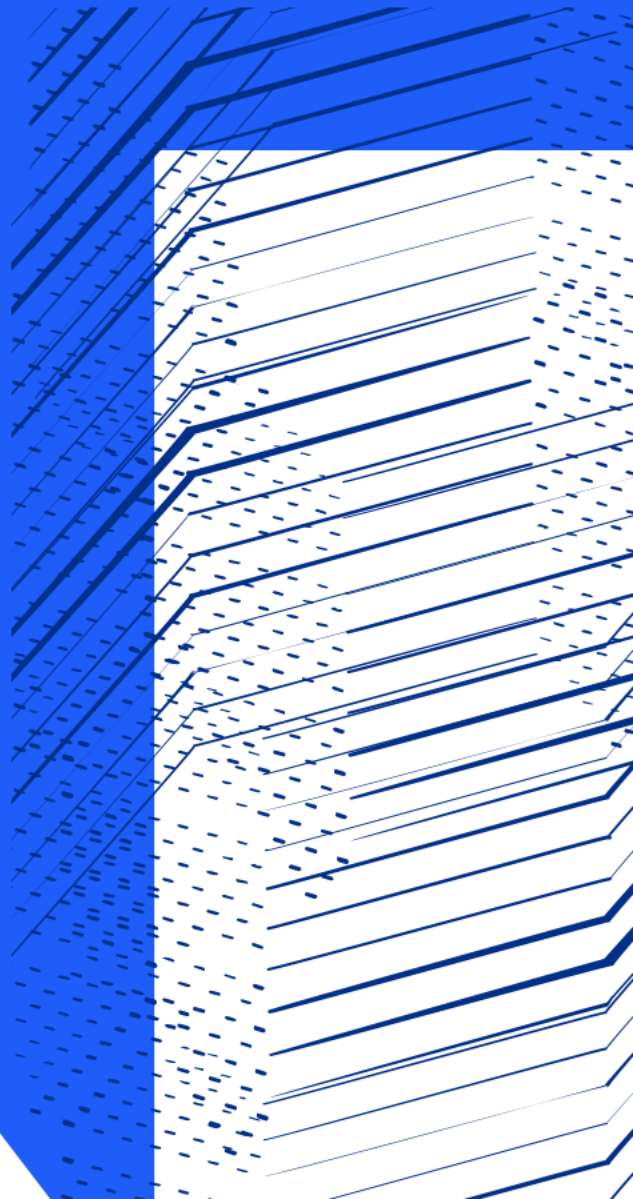
LBNF Target Exchange System (TXS) – Design Overview

Eric Harvey-Fishenden

(STFC Rutherford Appleton Laboratory)

LBNF Target Exchange System
Technical Design Review
24-25 June 2024



Science and Technology Facilities Council

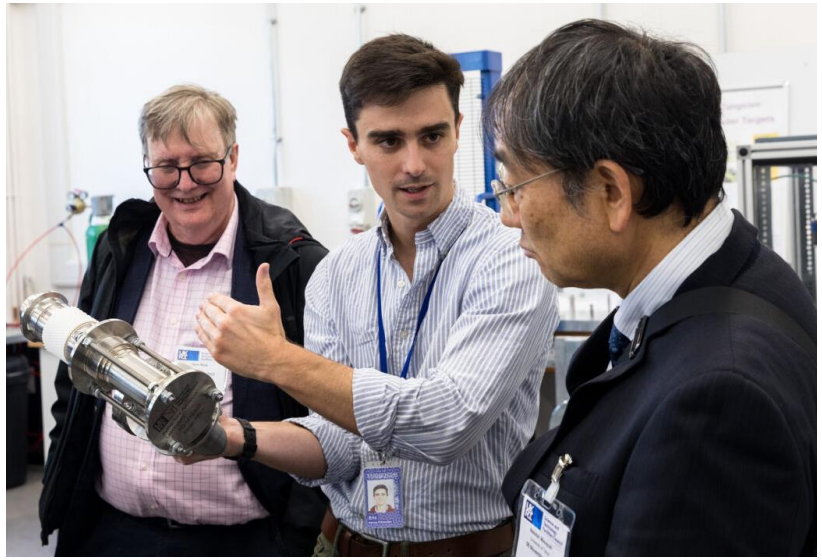
WARWICK
THE UNIVERSITY OF WARWICK

LBNF DUNE

Presenter Background

Eric Harvey-Fishenden

- Senior Mechanical Engineer
- RAL High Power Targets Group



Outline

1. LBNF Target Overview
2. Target Remote Handling Overview
    i. Target and Horn
    ii. LBNF-20 Work Cell
3. TXS Overview
    i. Mechanical design
    ii. Prototyping

UKRI Project Scope

Science and Technology Facilities Council

RAL / High Power Targets Group

- Project management
- Engineering design and construction
- Procurement
- Commissioning

WARWICK
THE UNIVERSITY OF WARWICK

University of Warwick

- Target: physics performance simulations

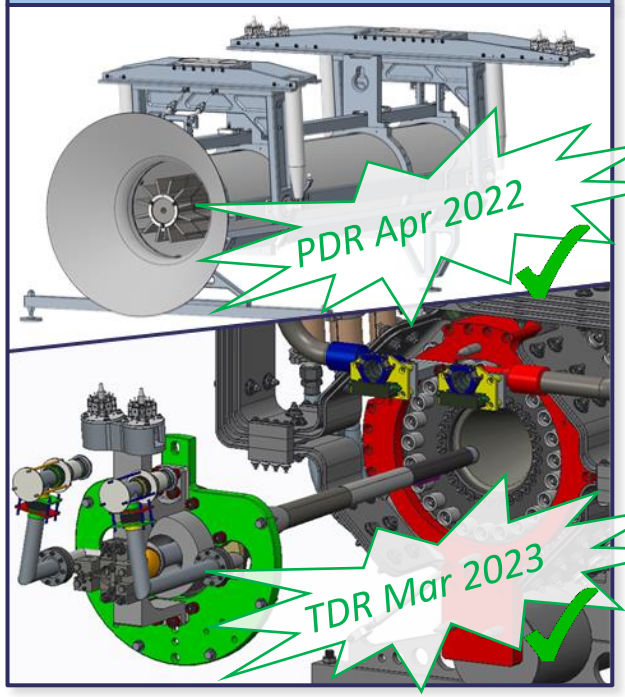
Birmingham / Bristol / Oxford / Culham

- Target: materials research

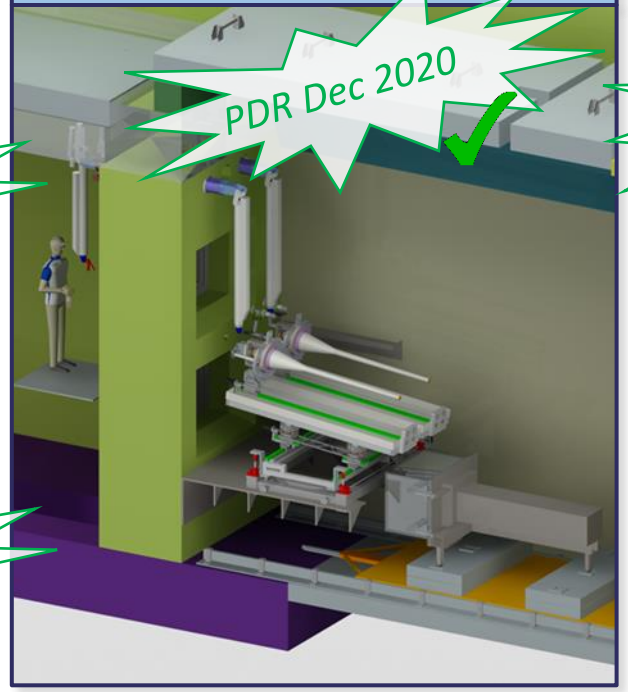
WP0: Project Management
PI: Densham / PM: Loveridge

This TDR: TXS

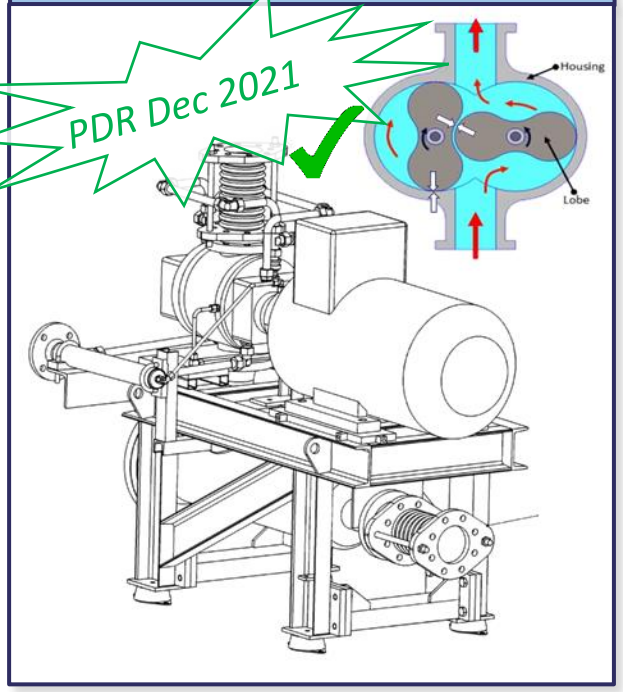
WP1
"Target and Beamline Apparatus"
(Loveridge)



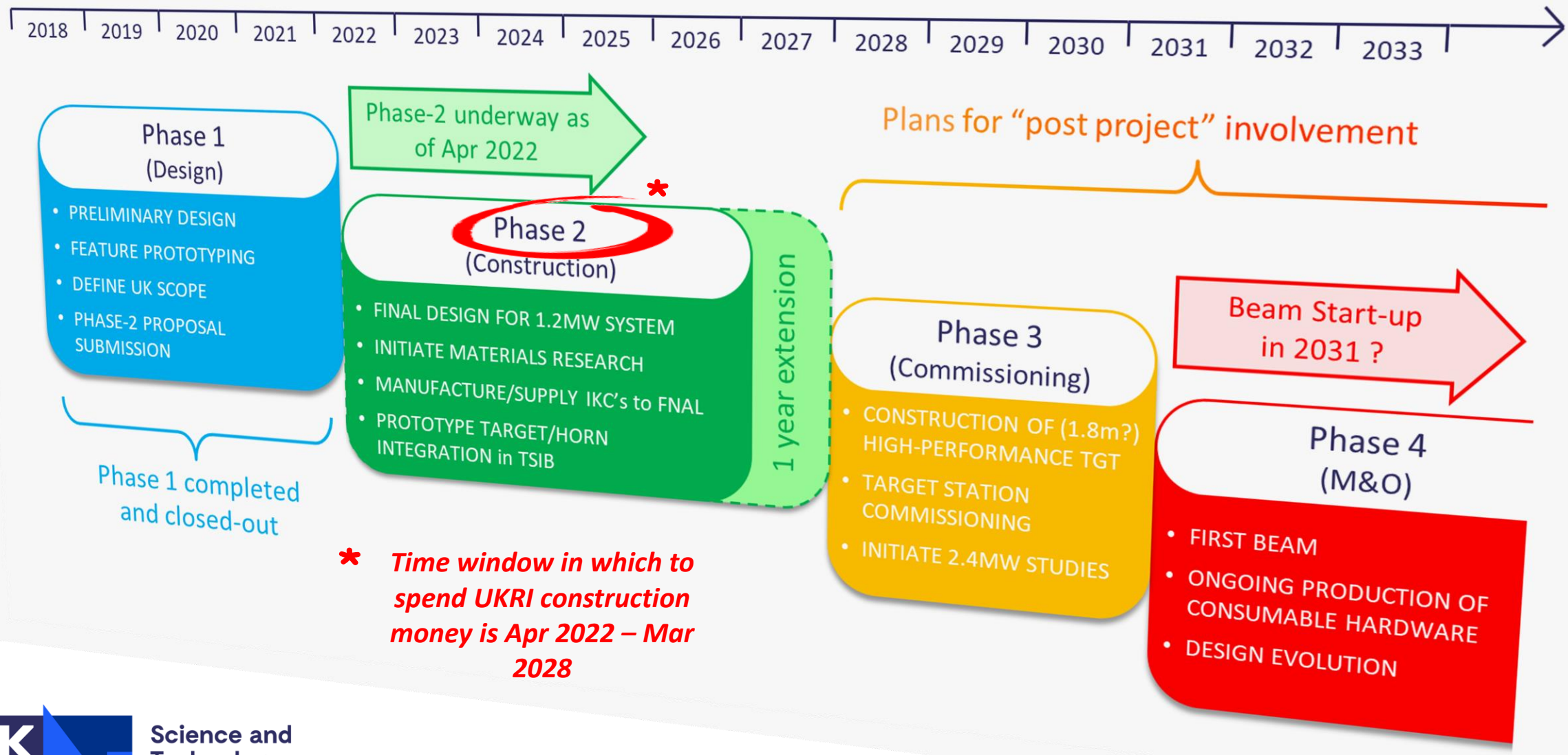
WP2
"Remote Handling"
(Harvey-Fishenden)



WP3
"Helium and Ancillary Plant"
(Parkin)



UK Project Timeline and Phases



* *Time window in which to spend UKRI construction money is Apr 2022 – Mar 2028*

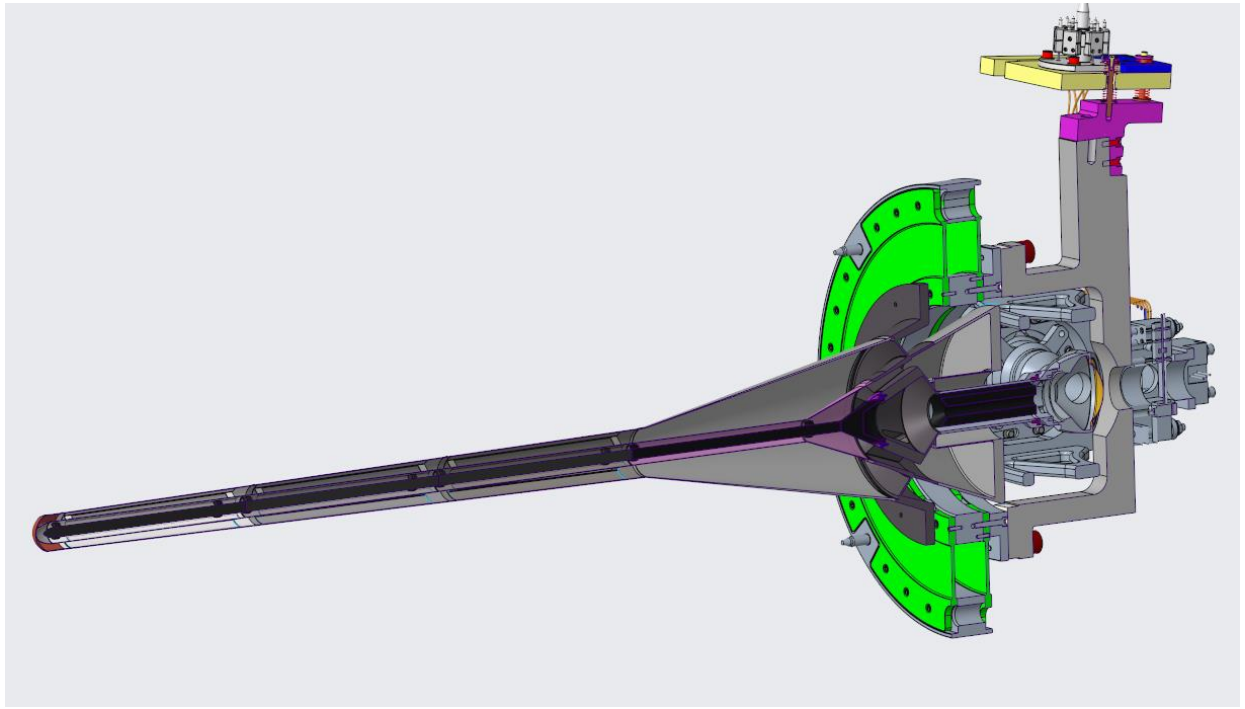
Science and Technology Facilities Council

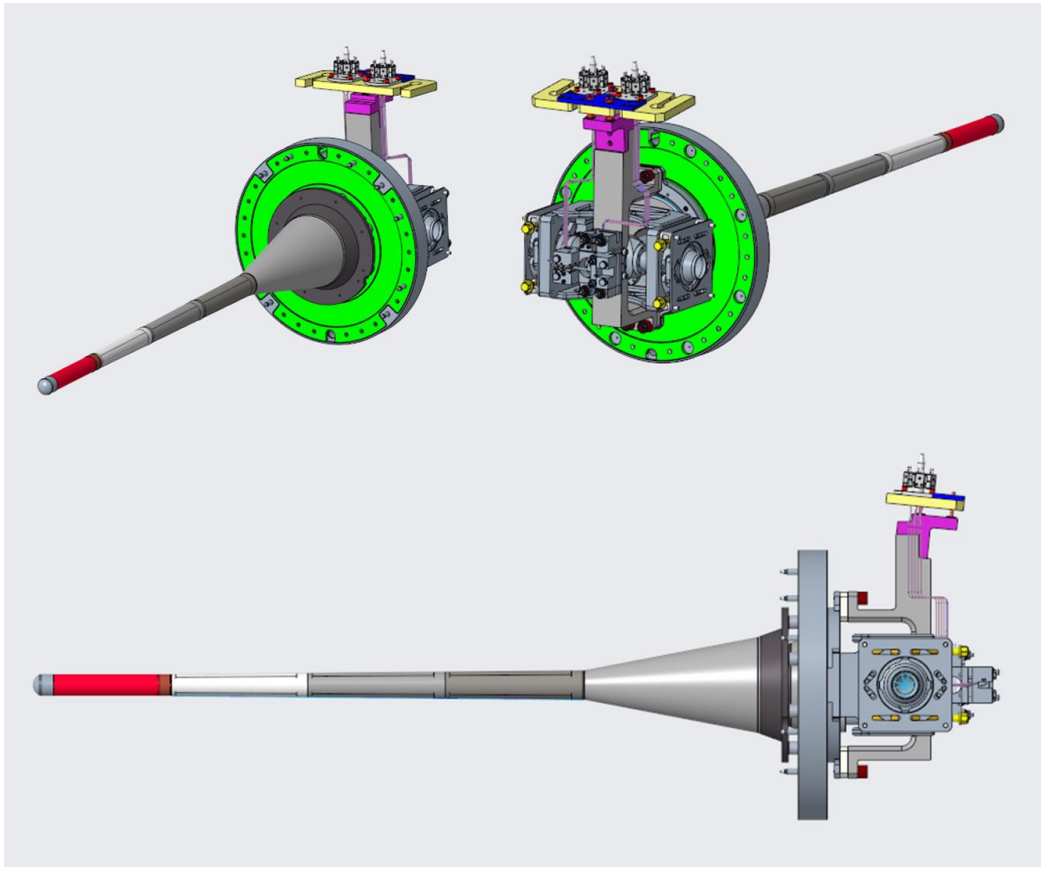
LBNF Target

- 1.5-1.8m of graphite rods encased in a titanium outer structure
- Overall length 2.2-2.5m (depending on length of graphite)
- Gas cooled with helium
- Total weight ~125kg
- “Consumable” item with expected lifetime c. 1 year
- Remote replacement to be carried out during planned maintenance periods in shielded work cell

Remote services connections:

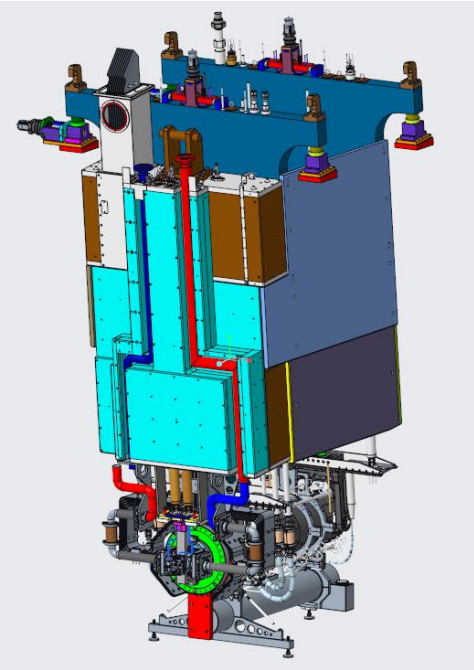
1. Helium inlet & outlet(Helicoflex seal, chain clamp design)
2. Instrumentation (2x6 thermocouple connectors)

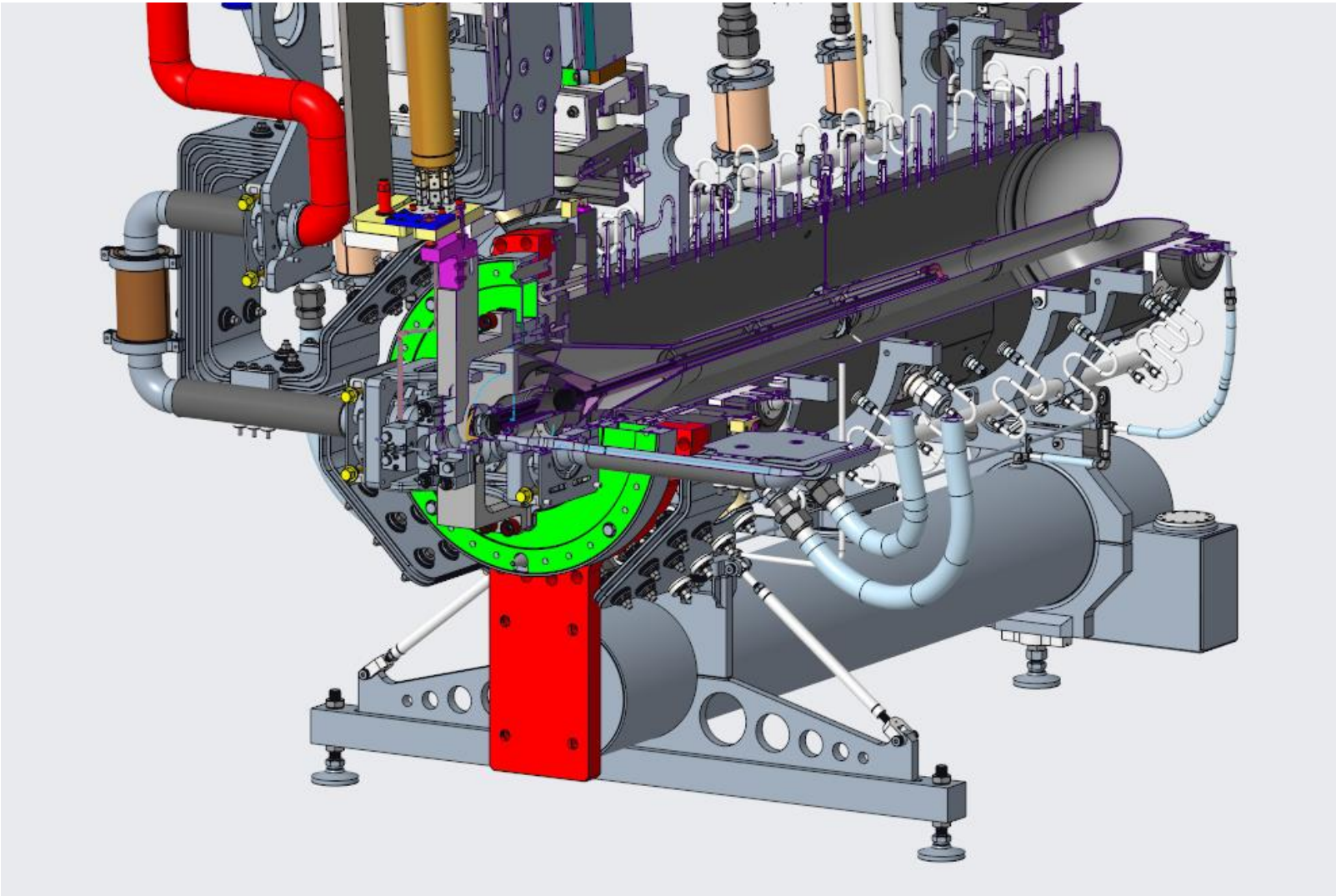




LBNF Target/Horn

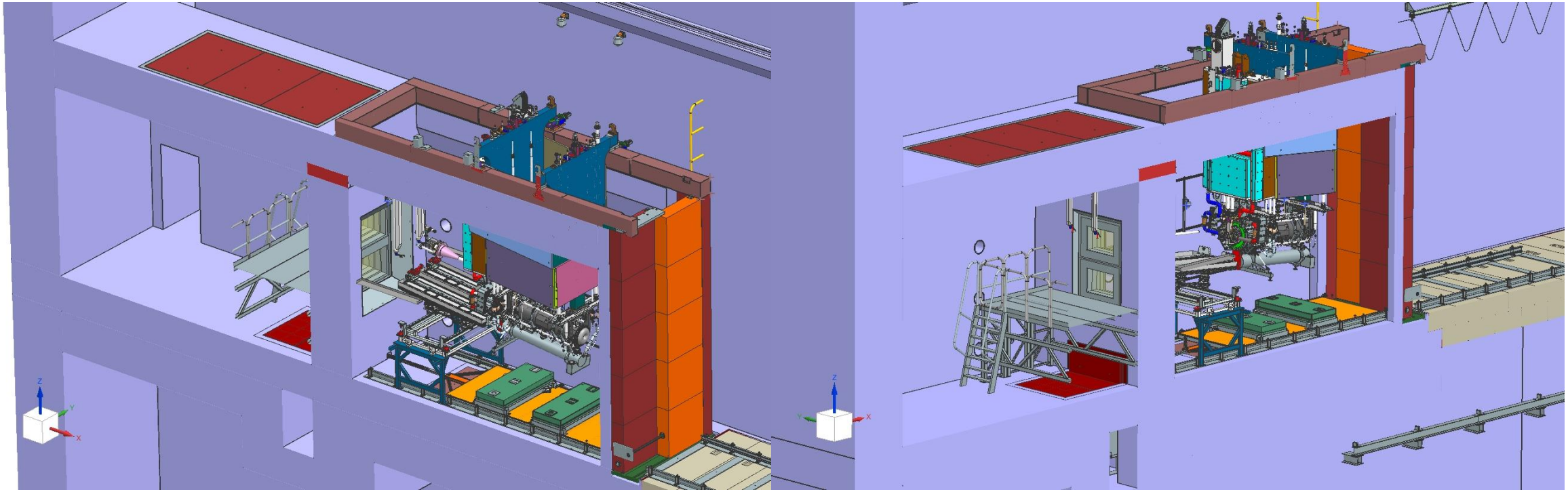
- LBNF Target supports are bolted directly to the Horn A (focussing electromagnet) inner conductor
- The target sits within the bore of the Horn A
- Features for attaching and aligning TXS are located on the target support plate (red)





Science and Technology Facilities Council

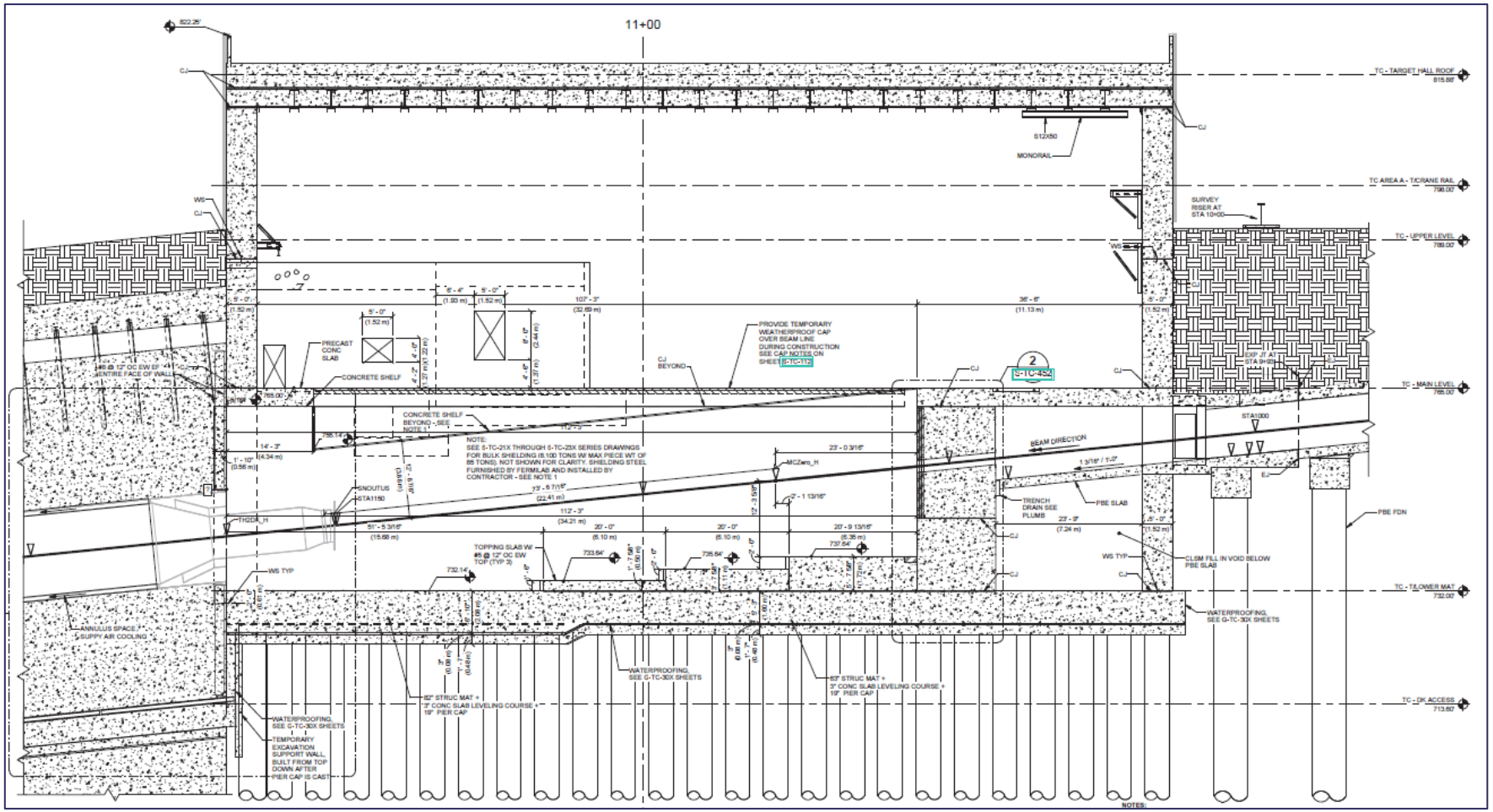
LBNF-20 Work Cell

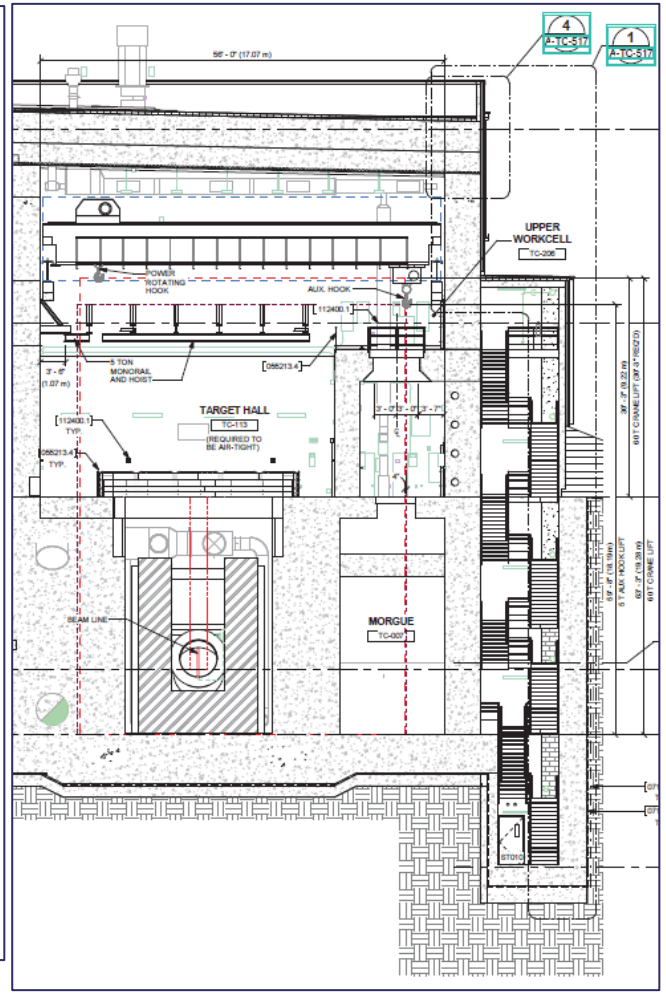


LBNF-20 work cell in target exchange configuration (Image M Sawtell)

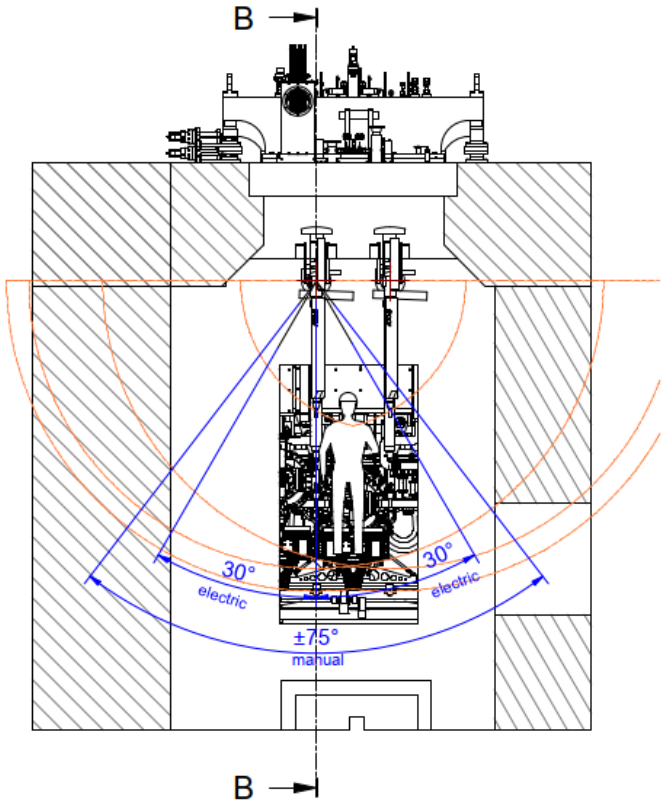
- Target replacement work takes place inside the shielded LBNF-20 work cell
- TXS is manually (crane assisted) installed and staged within the work cell
- Horn is remotely craned into the work cell once TXS is staged
- Long reach through-wall telemanipulators are used to handle tooling within the cell

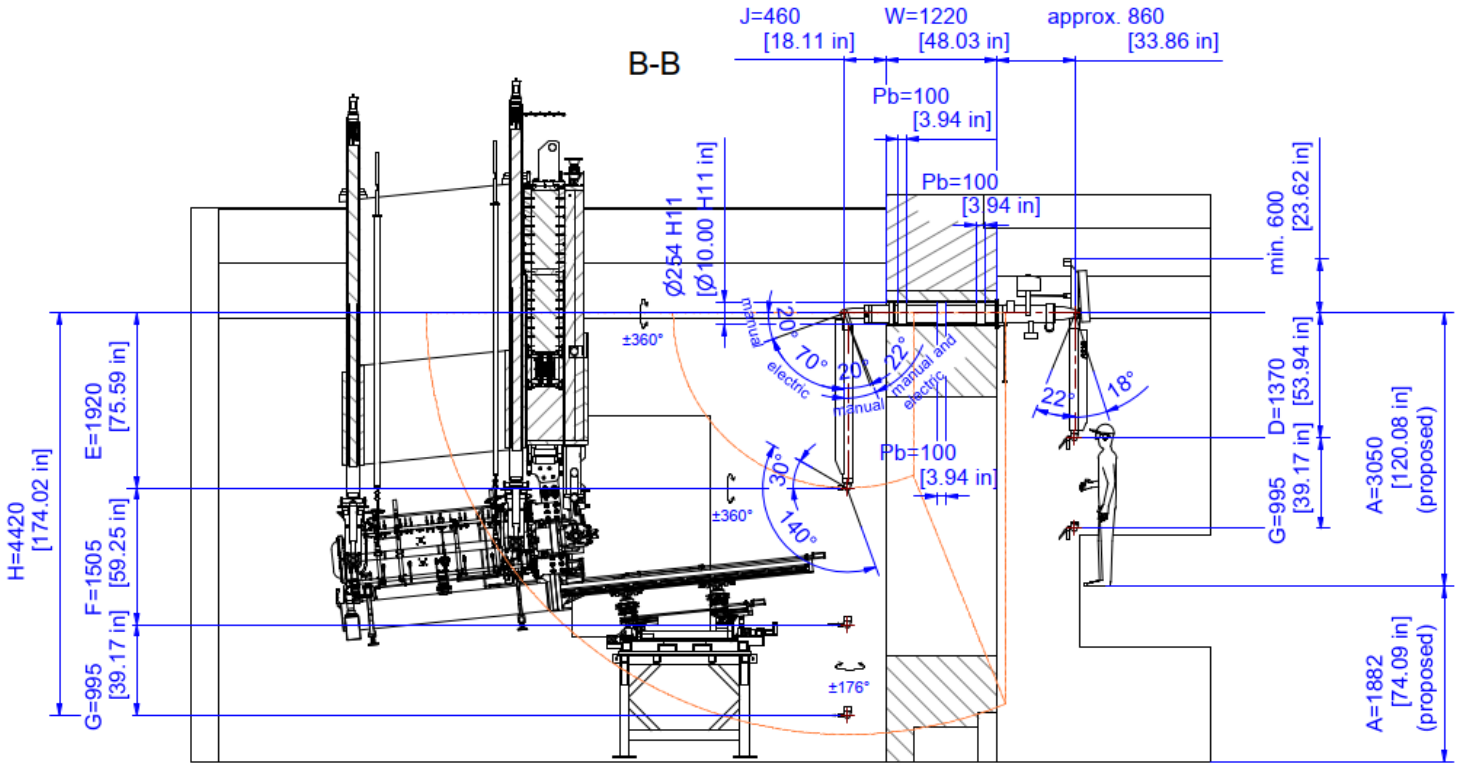
Target Complex



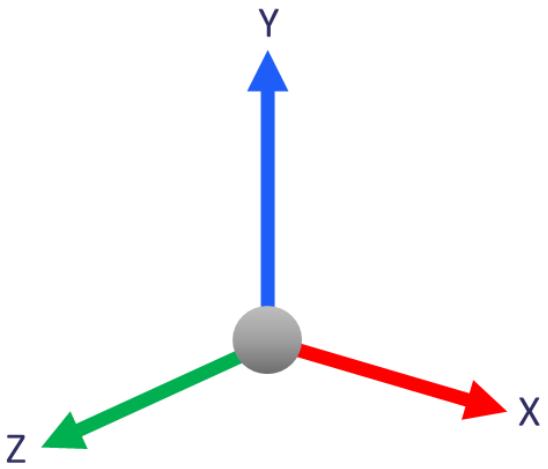


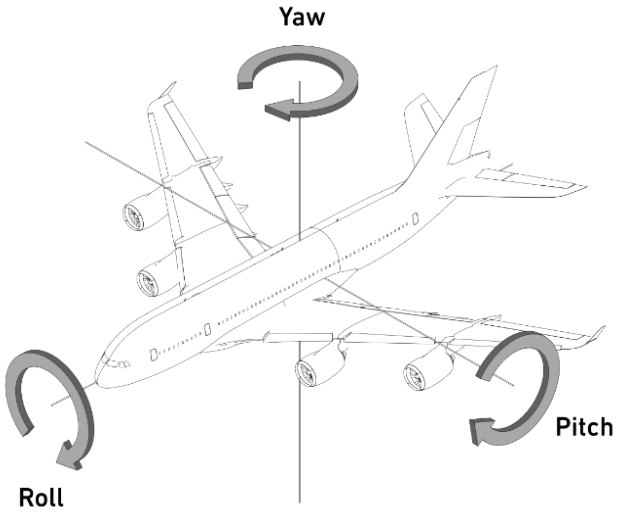
Work Cell Telemanipulator Coverage

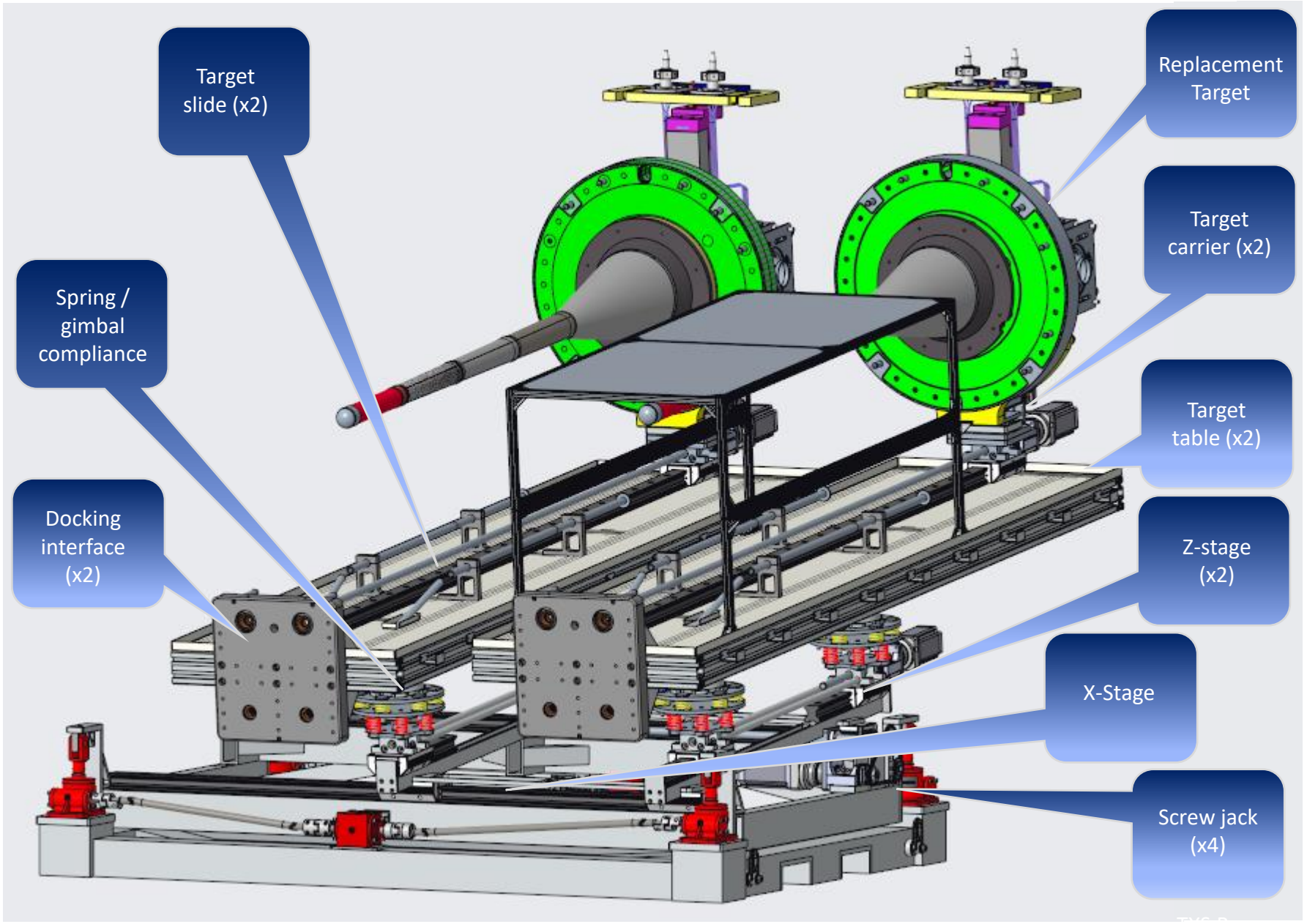




TXS Overview







Science and Technology Facilities Council

Key Milestones for the TXS

ID	Description	Forecast
1032MS6	TXS Technical Design Review Complete	2024/Q2
10018MS5	Manually operable TXS and dummy target delivered	2025/Q2
10056MS6	TXS and Remote Handling Equipment FDR Complete	2025/Q4
10016MS5	Remotely operable TXS delivered	2027/Q1

"Need-by" dates for UK deliverables defined in LBNF Near Site Project Schedule

131.NSCFB-Dec-W.03.03 Target Complex		27-Mar-23 A
131.NSCFB-Dec-W.03.03.00 Target Complex Milestones - Standard		02-Oct-23 A
131133.0300.2355MS5	T5 MS - Target Complex Pre-CD2 Design Complete	
131133.0300.2350MS5	T5 MS - Target Complex Preliminary Design Complete	
131133.0303.32040MS5	T5 MS - Delivery of Prototype Target Support System - RAL/PPD	
131133.0302.10008MS5	T5 MS - Delivery of He gas system Heat Exchangers - RAL/PPD	
131133.0303.32060MS5	T5 MS - Delivery of He gas system compressor - RAL/PPD	
131133.0302.10028MS5	T5 MS - Need-by Delivery of Prototype Target Support System - RAL/PPD	18-Aug-25
131133.0302.10033MS5	T5 MS - Need-by Delivery of Manual Target Exchange System and Dummy Target - RAL/PPD	16-Sep-25
131133.0303.32080MS5	T5 MS - Need-by Delivery of Prototype Target - RAL/PPD	11-Nov-25
131133.0302.10082MS5	T5 MS - Production Readiness Reviews Complete for all UKRI Deliverables - RAL/PPD	
131133.0302.10029MS5	T5 MS - Need-by Delivery of Prototype TPT - RAL/PPD	12-Mar-26
131133.0302.10011MS5	T5 MS - Delivery of Production Target Support System - RAL/PPD	
131133.0302.10010MS5	T5 MS - Delivery of He gas system Thru-TUB Helium gas lines - RAL/PPD	
131133.0302.10015MS5	T5 MS - Delivery of Target Container - RAL/PPD	
131133.0302.10030MS5	T5 MS - Need-by Delivery of Remote Manipulators - RAL/PPD	15-Oct-26
131133.0302.10007MS5	T5 MS - Delivery of Baffle / Carrier - RAL/PPD	
131133.0302.10016MS5	T5 MS - Delivery of Motorized Target Exchange System and Dummy Target - RAL/PPD	
131133.0302.10012MS5	T5 MS - Delivery of Production TPT - RAL/PPD	
131133.0303.32090MS5	T5 MS - Delivery of Production Target - RAL/PPD	
131133.0302.10083MS5	T5 MS - Shipping Acceptance Reviews Complete for all UKRI Deliverables - RAL/PPD	22-Mar-27
131133.0303.32120MS5	T5 MS - Complete documentation package of all UK deliverables - RAL/PPD	
131133.0302.10024MS5	T5 MS - Need-by Delivery of Helium Gas System Purity Monitoring System - RAL/PPD	24-Aug-27
131133.0302.10023MS5	T5 MS - Need-by Delivery of Helium Gas System Heat Exchangers - RAL/PPD	16-Dec-27
131133.0302.10022MS5	T5 MS - Need-by Delivery of Helium Gas System Compressor - RAL/PPD	14-Jul-28
131133.0302.10025MS5	T5 MS - Need-by Delivery of Helium Gas System Thru-TUB Helium gas lines - RAL/PPD	31-Jul-28
131133.0302.10026MS5	T5 MS - Need-by Delivery of Production Target Support System - RAL/PPD	08-Jan-29
131133.0302.10021MS5	T5 MS - Need-by Delivery of Baffle / Carrier - RAL/PPD	22-Feb-29
131133.0302.10032MS5	T5 MS - Need-by Delivery of Motorized Target Exchange System - RAL/PPD	11-May-29
131133.0303.32100MS5	T5 MS - Need-by Delivery of Production Target - RAL/PPD	11-May-29
131133.0302.10027MS5	T5 MS - Need-by Delivery of Production TPT - RAL/PPD	08-Aug-29
131133.0302.10031MS5	T5 MS - Need-by Delivery of Target Container - RAL/PPD	20-Aug-29
131133.0300.2360MS5	T5 MS - Target Complex Fabrication Procurement Complete	
131133.0300.2380MS5	T5 MS - Target Complex Installation / Checkout Complete	

OK

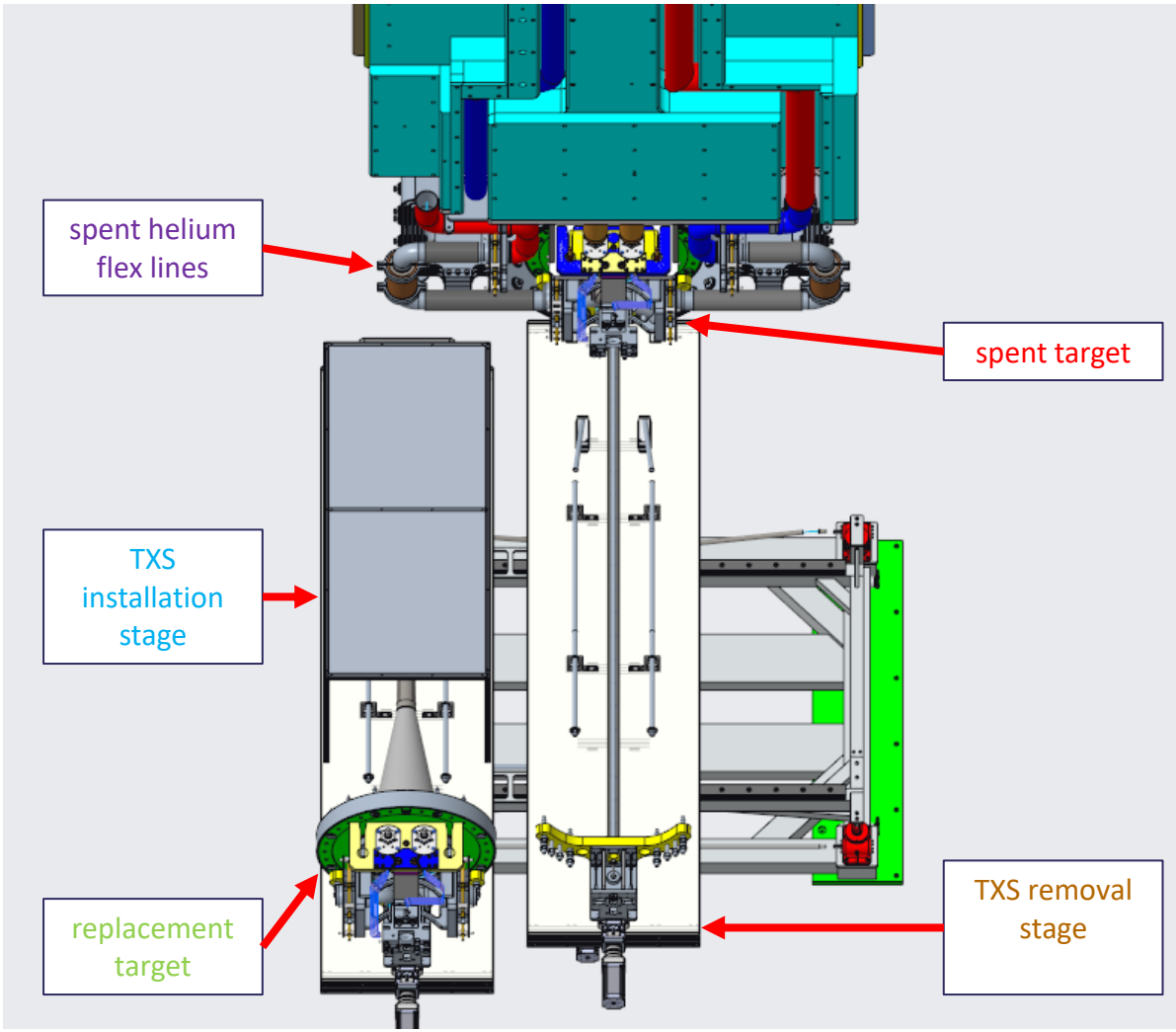
OK

Science and Technology Facilities Council

Target Exchange Procedure Overview

1. Remove shielding from work cell
2. Install and stage TXS & replacement target in LBNF-20 work cell
3. Crane in Horn A & spent target
4. Replace shielding onto work cell
5. Disconnect spent helium flex lines from target and store*
6. Align and dock TXS removal stage to Horn A
7. Drive target carrier to spent target and make bolted connection
8. Undo target bolted connections
9. Extract spent target
10. Disconnect & retract TXS removal stage
11. Align and dock TXS installation stage to Horn A
12. Drive new target into Horn support location
13. Make replacement target bolted connections
14. Disconnect and retract TXS installation stage
15. Install and connect new helium flex lines

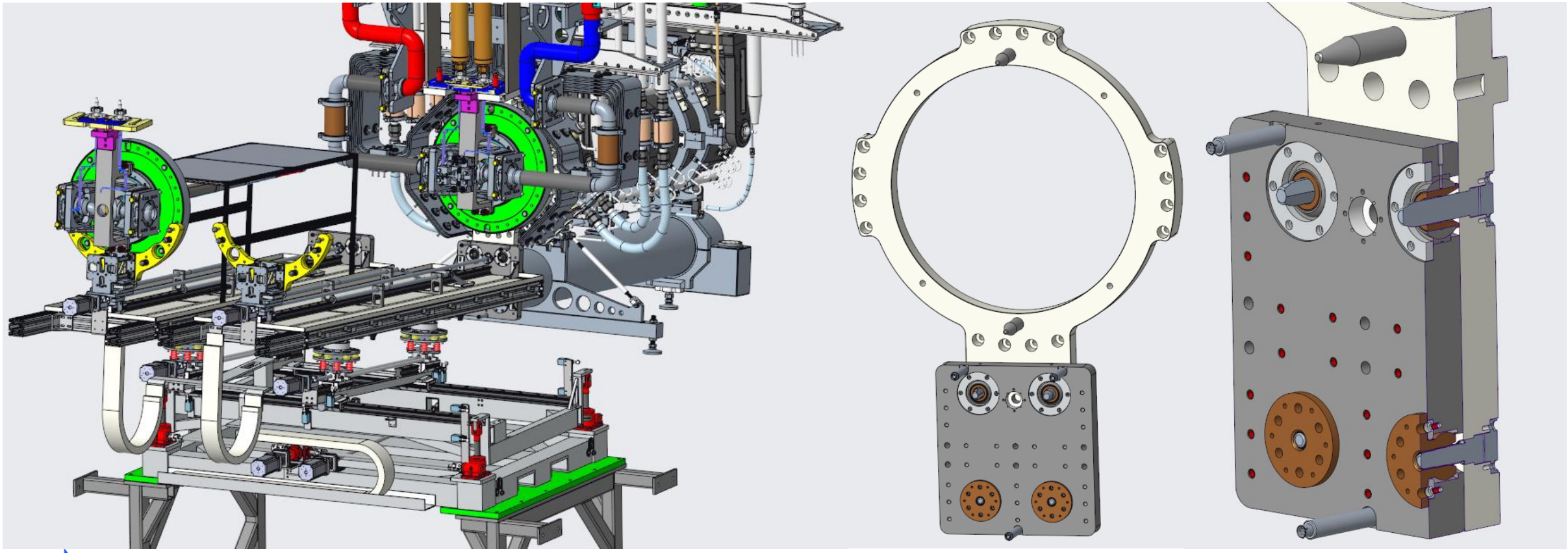
**Helium flex line exchange tooling concept is under development*



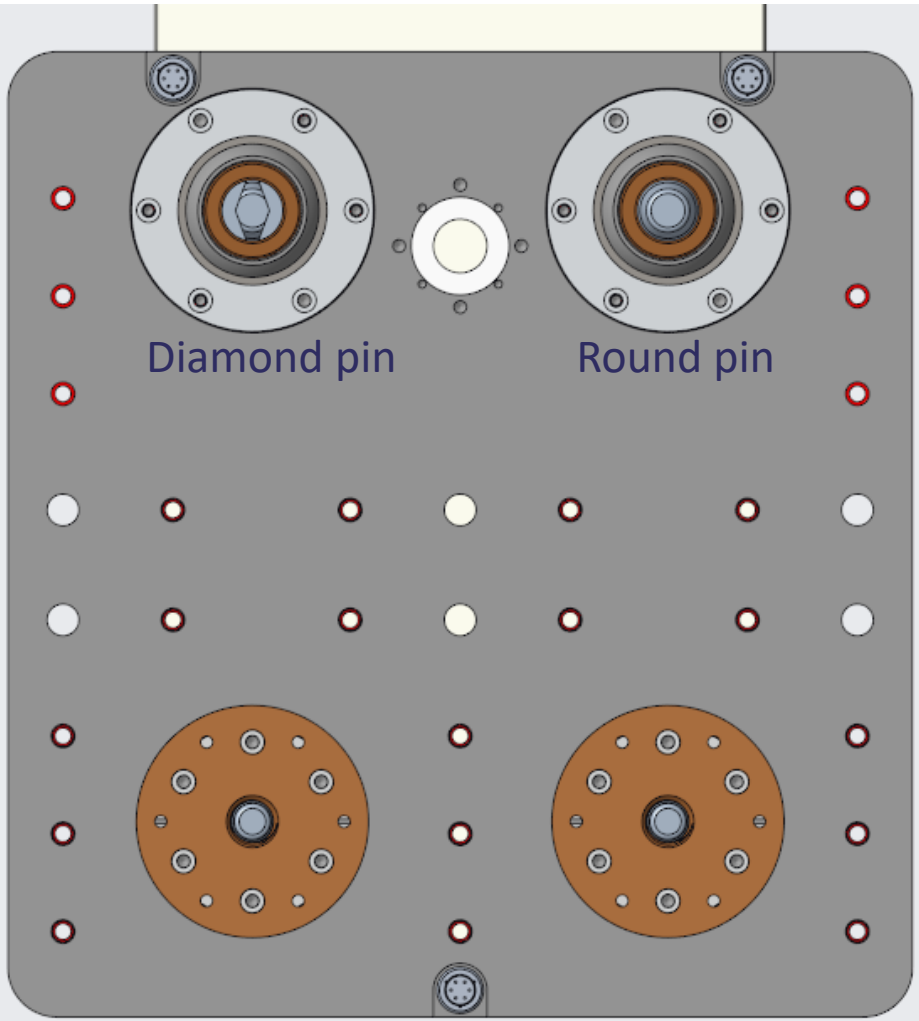
Science and Technology Facilities Council

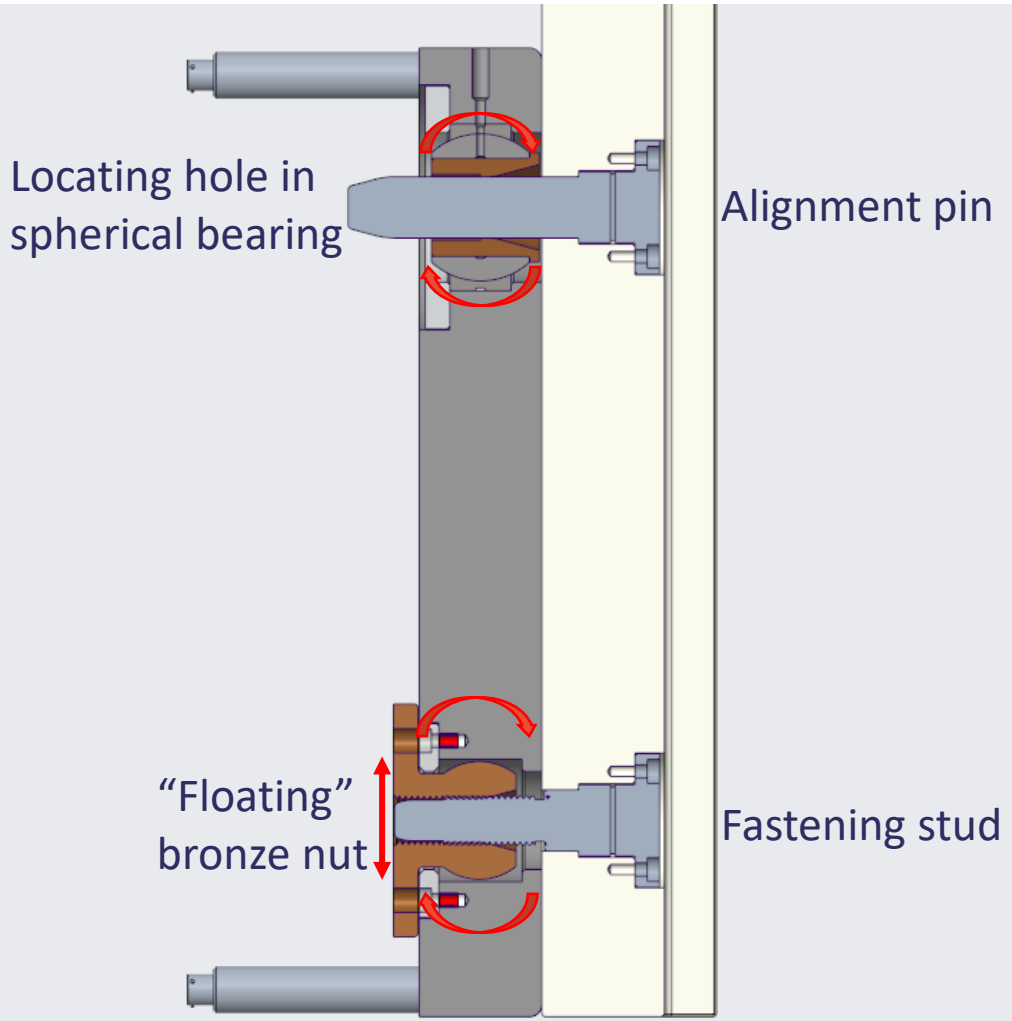
TXS Alignment/Docking

- To align to the target supports on Horn A for target installation/removal, the TXS mechanically “docks” to it
- There are two docking stages – one for spent target removal (R), one for new target installation (L)
- Positioning for docking is done via motor driven X,Y, Z and pitch adjustment. Sprung compliance allows for some misalignment and allows for roll/yaw movement

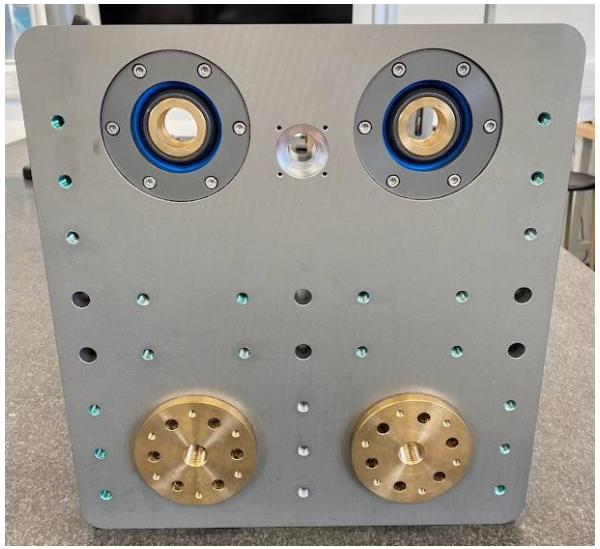


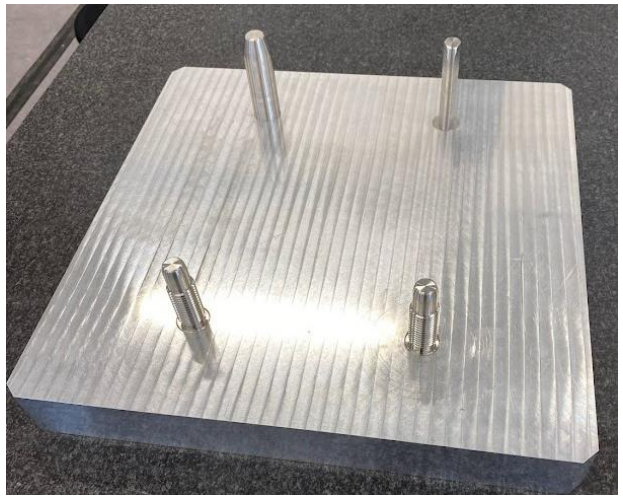
TXS Alignment/Docking

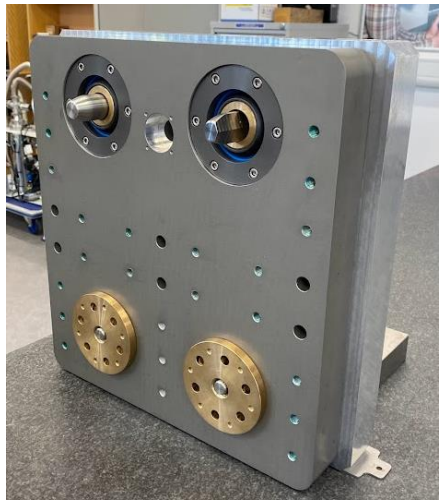


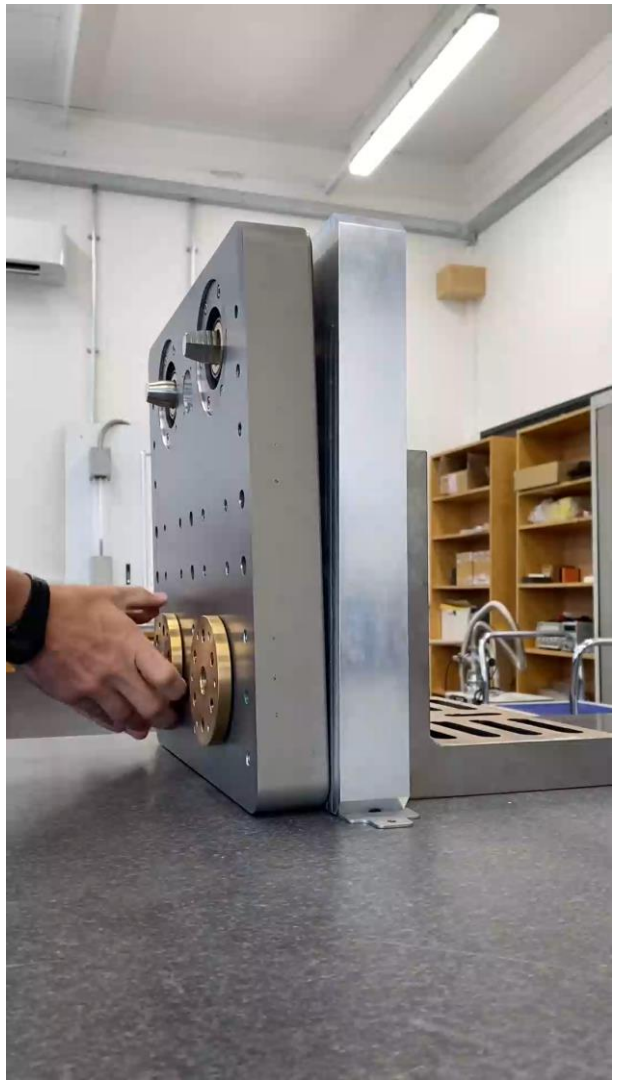


Feature Prototyping – Docking mechanism







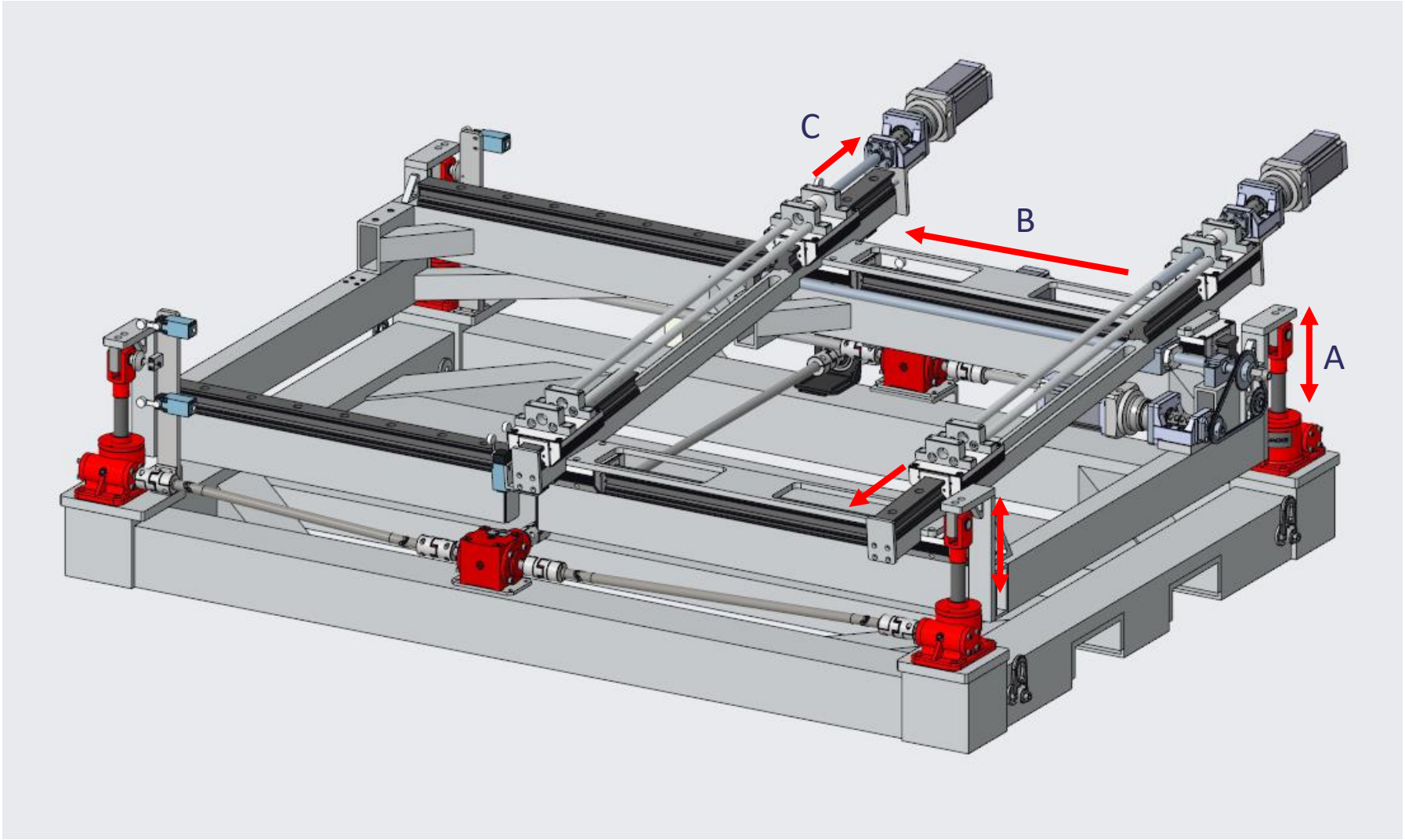


Docking Positional Adjustment

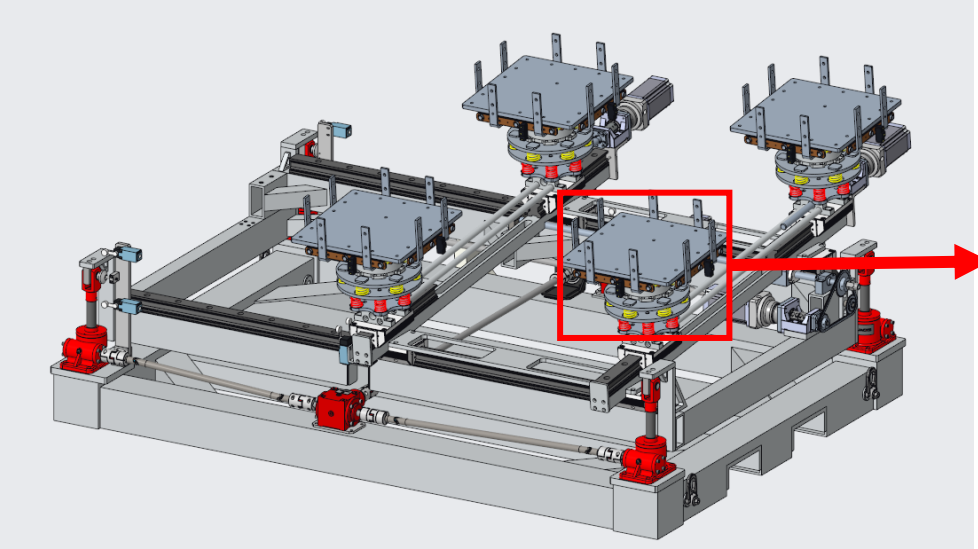
A. Y and pitch adjusted using front and rear screw jacks
   - Stepper motor driven in T-configuration using a gearbox and double UJ shafts (mounted at rear of TXS)
   - 150mm travel

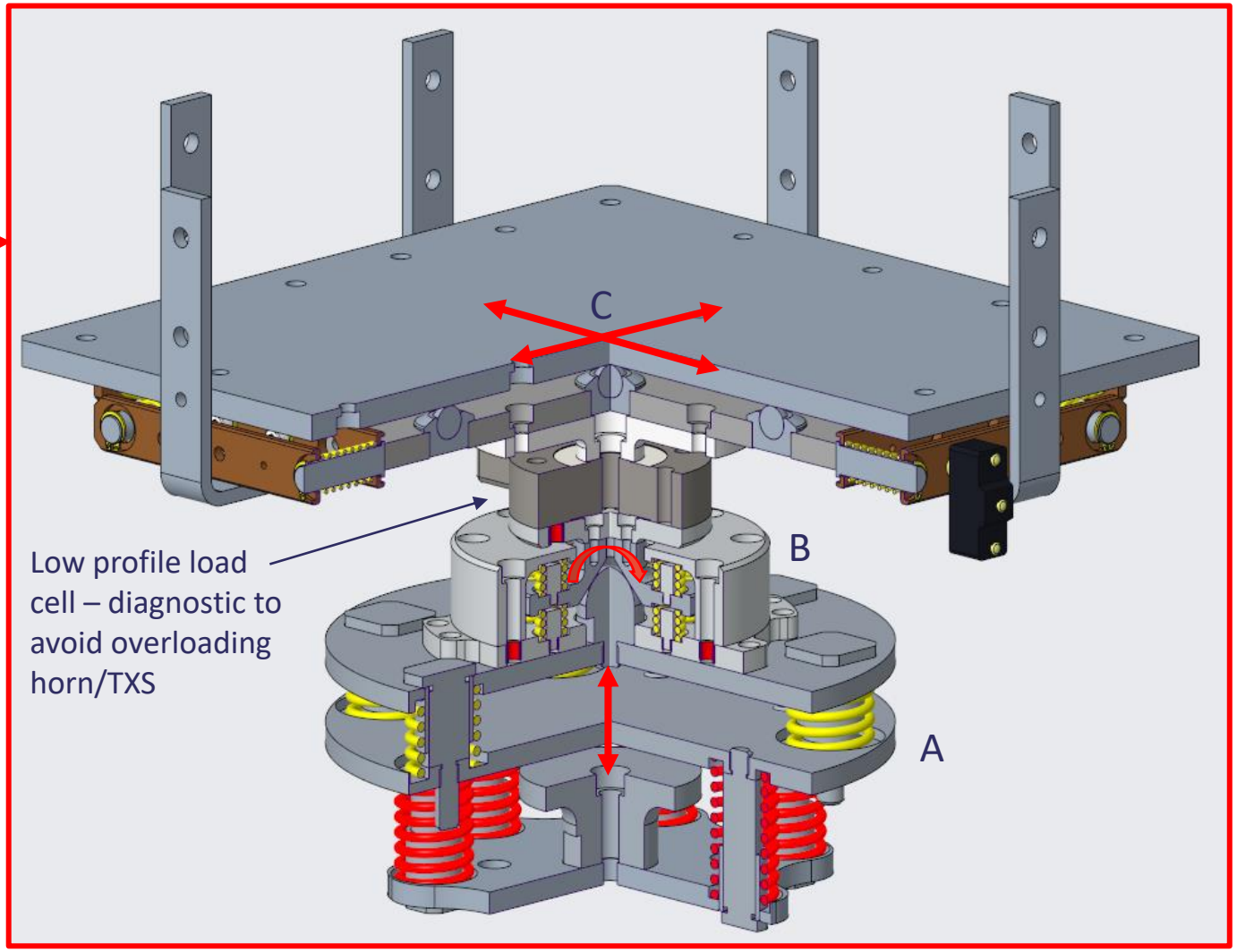
B. X adjusted using double horizontal linear carriages
   - Stepper motor driven ball screw (mounted inboard using reduction chain drive)
   - Used to select between installation and removal stages
   - 850mm travel

C. Z adjusted for each stage using linear carriages
   - Stepper driven ball screw
   - Tilted down at beamline angle (5.8º)
   - One each for installation and removal stages
   - 207.5mm travel



Docking Positional Compliance





A. Spring supports – Y compliance (20mm)
   - Lower free springs offer compliance when screw jacks are adjusted
   - Upper pre-compressed springs avoid overloading damage

B. Gimbal – Angular (pitch, roll) compliance (±2º)
   - Spring centered gimbal allows angular compliance

C. Ball transfer stage – X, Z, yaw compliance (±15mm)
   - Spring centered ball transfer stage allows for XZ planar misalignments
   - Plunger microswitches installed to indicate limits of compliance

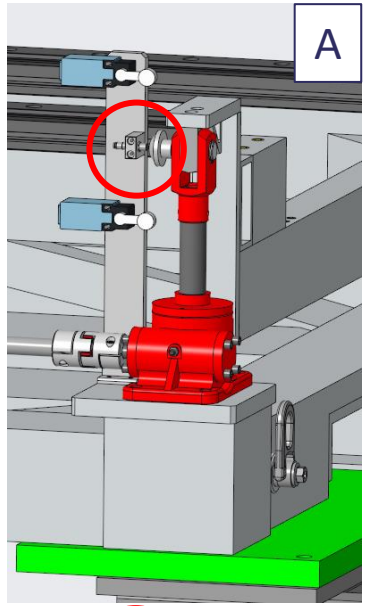
Docking Diagnostics/Feedback

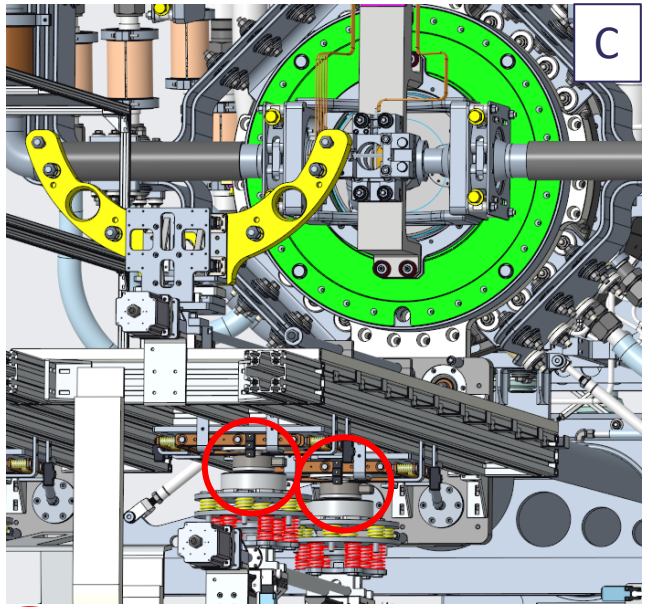
A. Precision limit (datum) switches in nominal positions on linear axes (X,Y,Z)

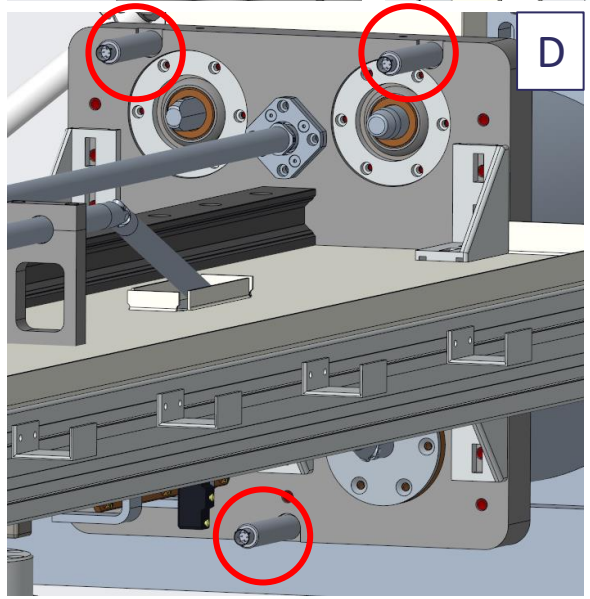
B. Visual guide indicators on target support plate/TXS docking interface
   - Not currently modelled but likely using horizontal/vertical fiducials to line up with laser markings on components

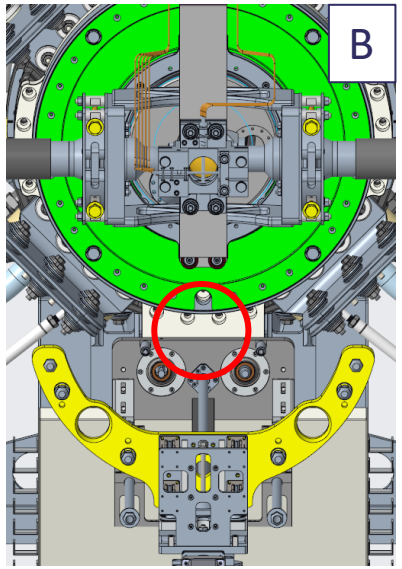
C. Load cells (front and rear) on each docking stage
   - Indicate whether stage is too high/too low
   - Indicate angular misalignment (pitch)
   - Red/Amber/Green indicators on control HMI depending on whether readings are within safe range

D. 3x proximity sensors (LVDTs) at each docking interface
   - 3x 13mm travel LVDTs give indication of distance and angular misalignment during docking process
   - Confirm face-to-face contact is achieved at docking interface









Target Installation/Removal

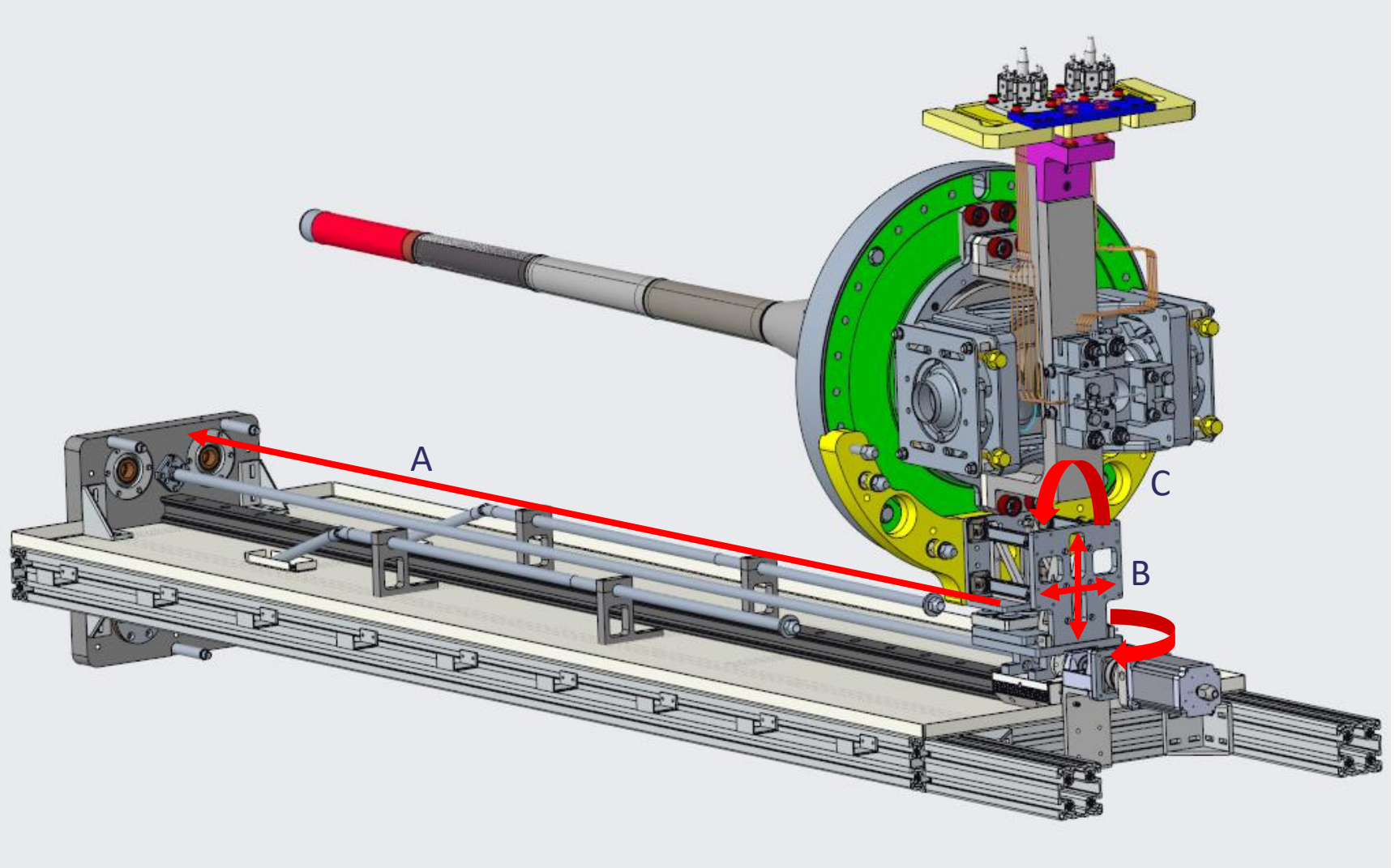
- Docking provides alignment for target installation removal
  - Positional accuracy at upstream end approx. ±0.5mm
  - Angular accuracy of target table around 3mm/m (0.2º)
- Alignment pins for target installation have 10-20µm clearance
  - We need some compliance on the target carrier mechanism to allow the target to align to its supports without binding or galling

Target Installation/Removal

A. Target insertion stage (2450mm linear rail)
   - Stepper driven ball screw

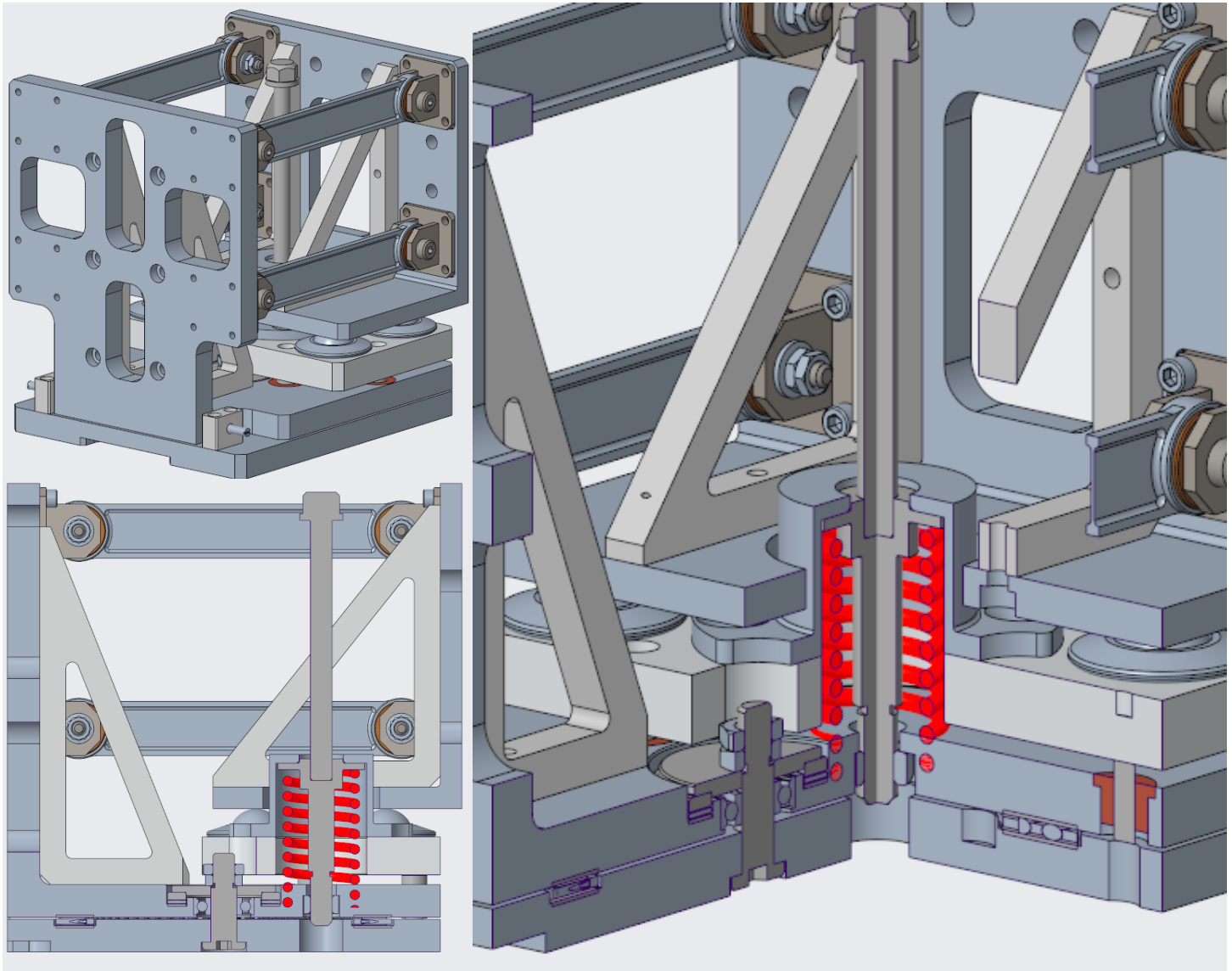
B. Target compliance mechanism
   - Multi DOF compliant mechanism based around a slewing bearing and a sprung planar 4-bar linkage

C. Target carrier
   - Interface for target attachment to TXS – target fixed to carrier with 4x captive bolts



Target Compliance Mechanism (TCM)

- 2x parallel 4 bar linkages
- Slender horizontal links for lateral and rotational compliance
- Ball transfer units to permit smooth lateral motion but minimise angular rotation
- Pre-compressed spring allows vertical motion but means position of TCM is consistent with or without the mass of a target
- Spring centred on a slewing bearing (2x thrust bearings and one deep groove ball bearing
- Some design updates planned but not yet implemented:
  - Increased spring rate to match latest target mass estimates
  - Thickened horizontal links to accommodate increased target mass
  - Hard stops to prevent over-rotation (roll)

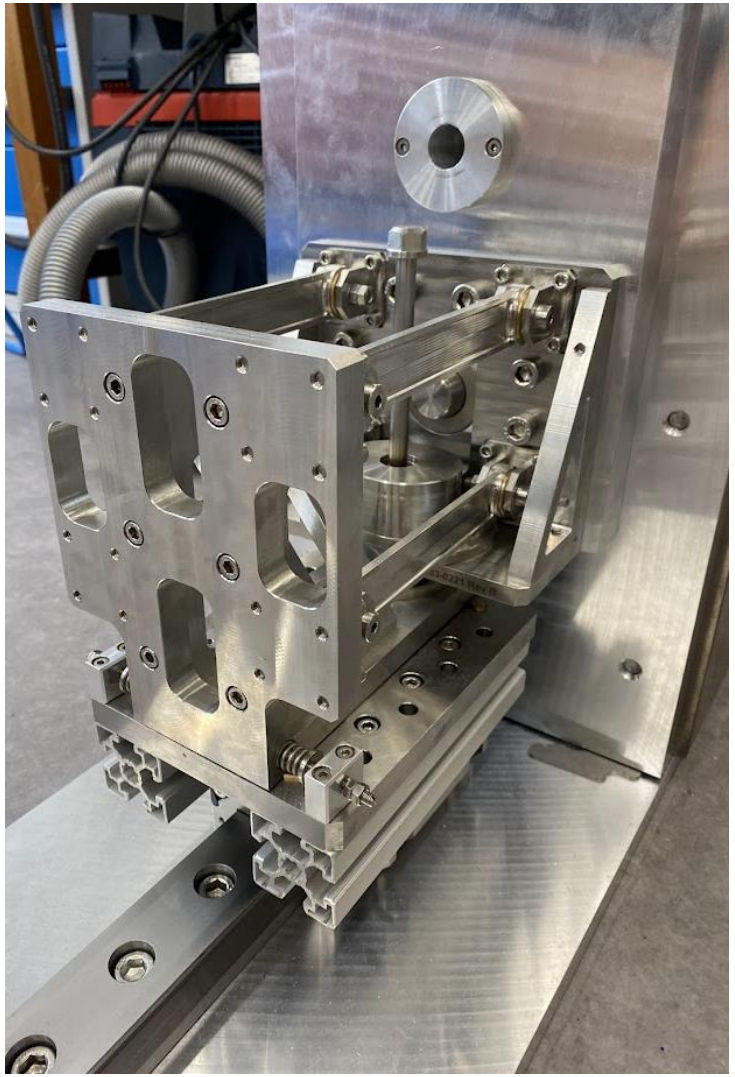


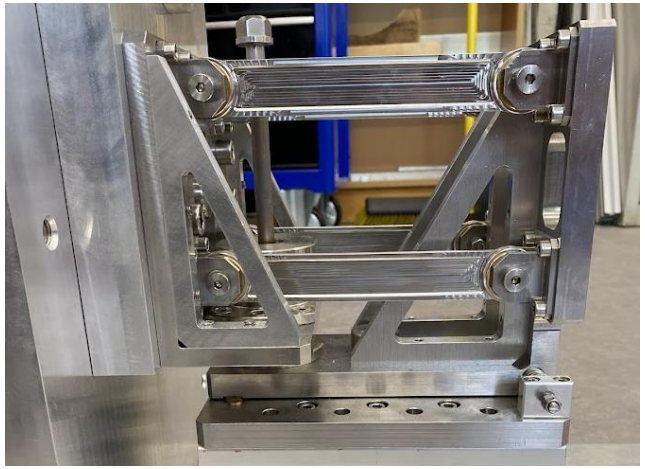
Feature Prototyping

2 iterations (V1,V2) of a TCM have been manufactured, assembled and tested

This has proved capable of locating a representative target mass, onto alignment pins representative of the target support with misalignments in X, Y, pitch and roll of up to ±2mm

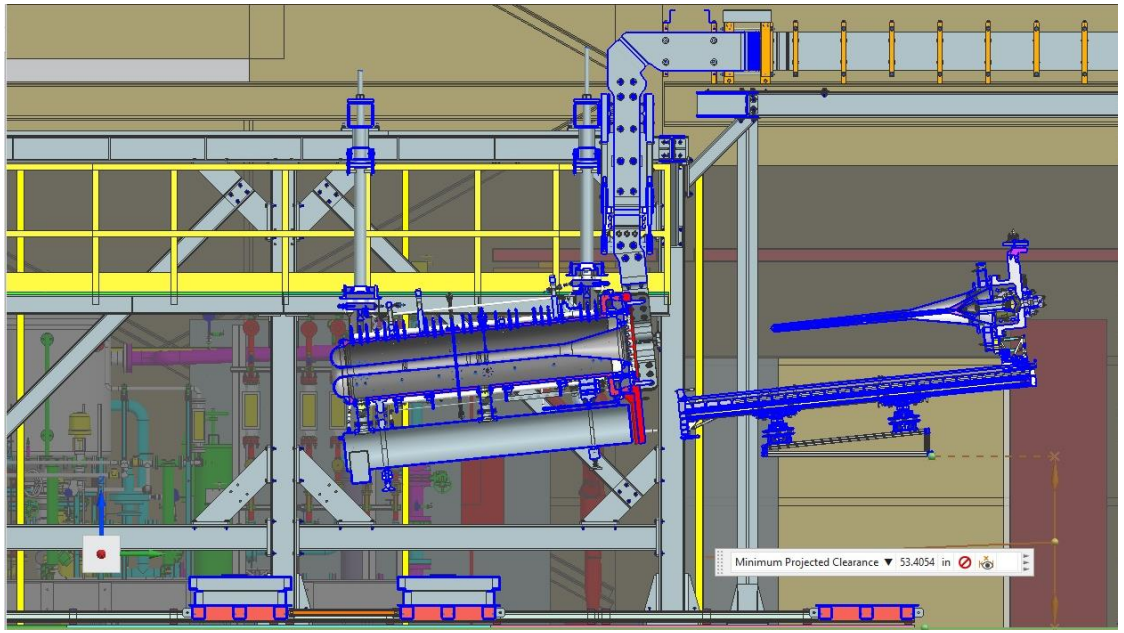
Improvements from V2 have been incorporated into the latest design (needle roller bearings, ball transfer units)

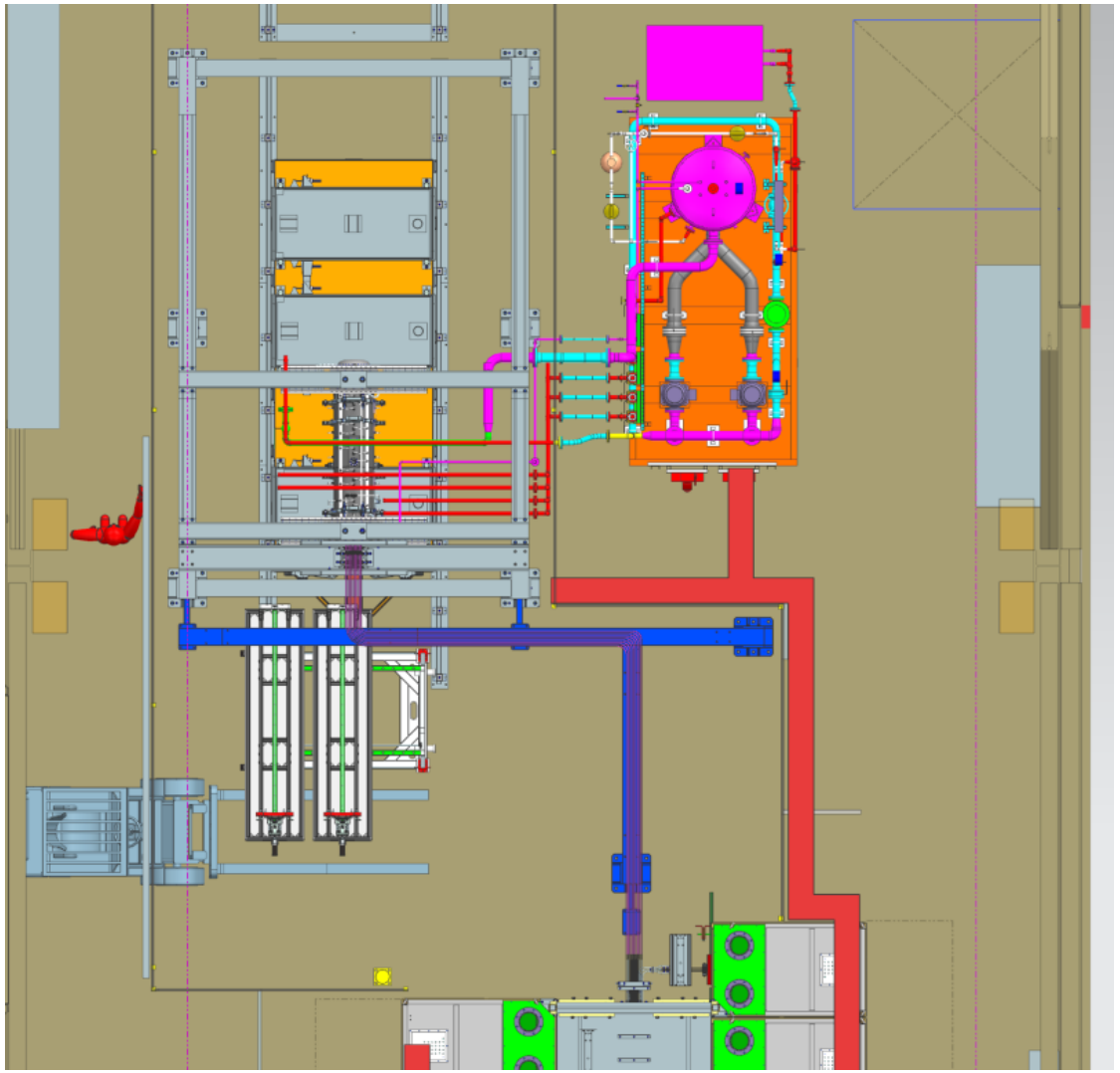




Manual TXS

- Pulse testing of a prototype target inside a prototype horn A is currently planned for late 2025.
- This is well in advance of the need by date for a fully integrated electromechanical TXS
- A method is required for installing/removing target into horn
- This is an opportunity to test out a reduced scope prototypic “manual” TXS





Manual TXS

- Single stage reduced scope version of the LBNF TXS for use in an offline, non-radioactive environment
- Requirement is to install and remove a single target rather than replace “old” for “new”

- Motion control system may not be integrated at this point, hence provision for “manual” control using hand tools or hand-wheels.
- Docking interface, compliance mechanisms all prototypic versions of those to be used on the full system
- Lift table/cart to be used for height adjustment to the working height of the horn pulse test stand

- Gives us the opportunity to use manual TXS and lessons learnt/improvements will feed into TXS FDR (Dec 2025) and full TXS build (by Q1 2027)

Science and
Technology
Facilities Council

Questions?