

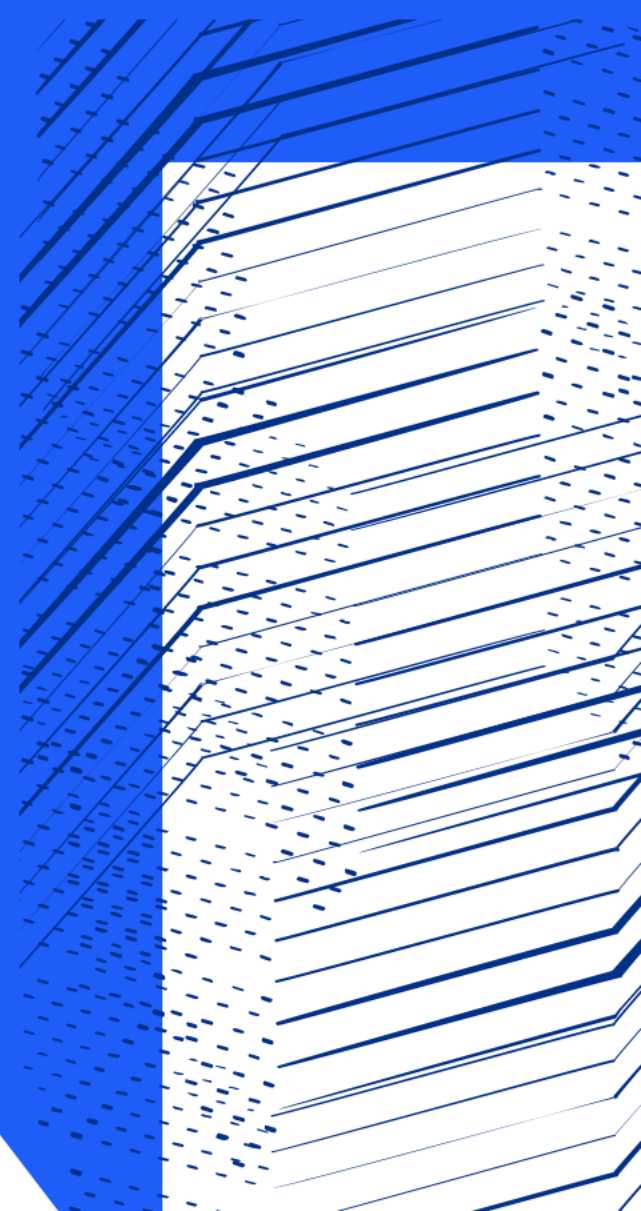


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PIP-II Status Update

Peter McIntosh – Principal Investigator
Jon Lewis – Project Manager

LBNF/DUNE UK Meeting
4th – 5th Jul 2022



Agenda

1 Recap – Project Goals

A brief reminder of PIP-II's major outputs

2 Milestones Achieved

An update of successes since Jan

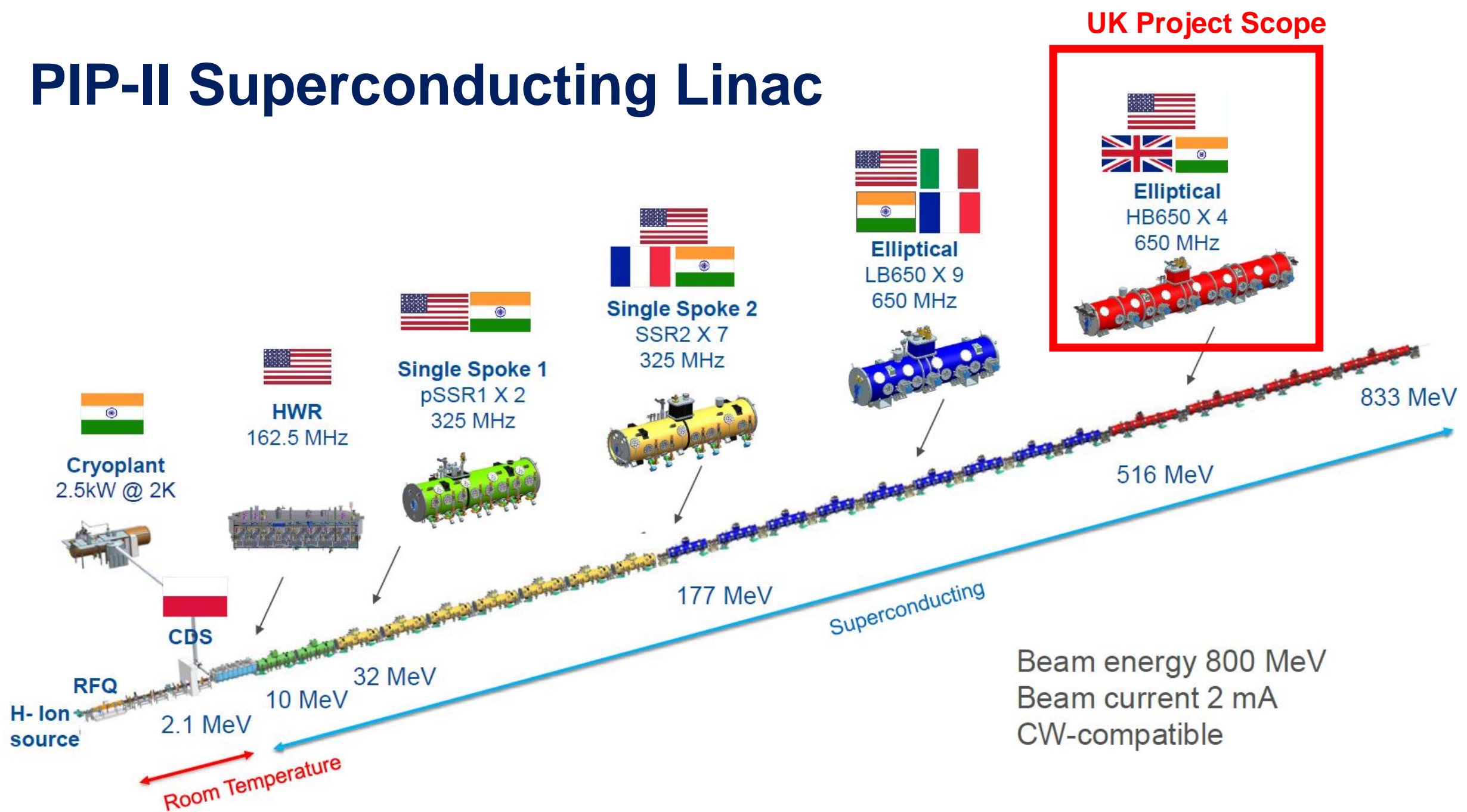
2 Project Update

Update on project progress since Jan

4 Conclusions



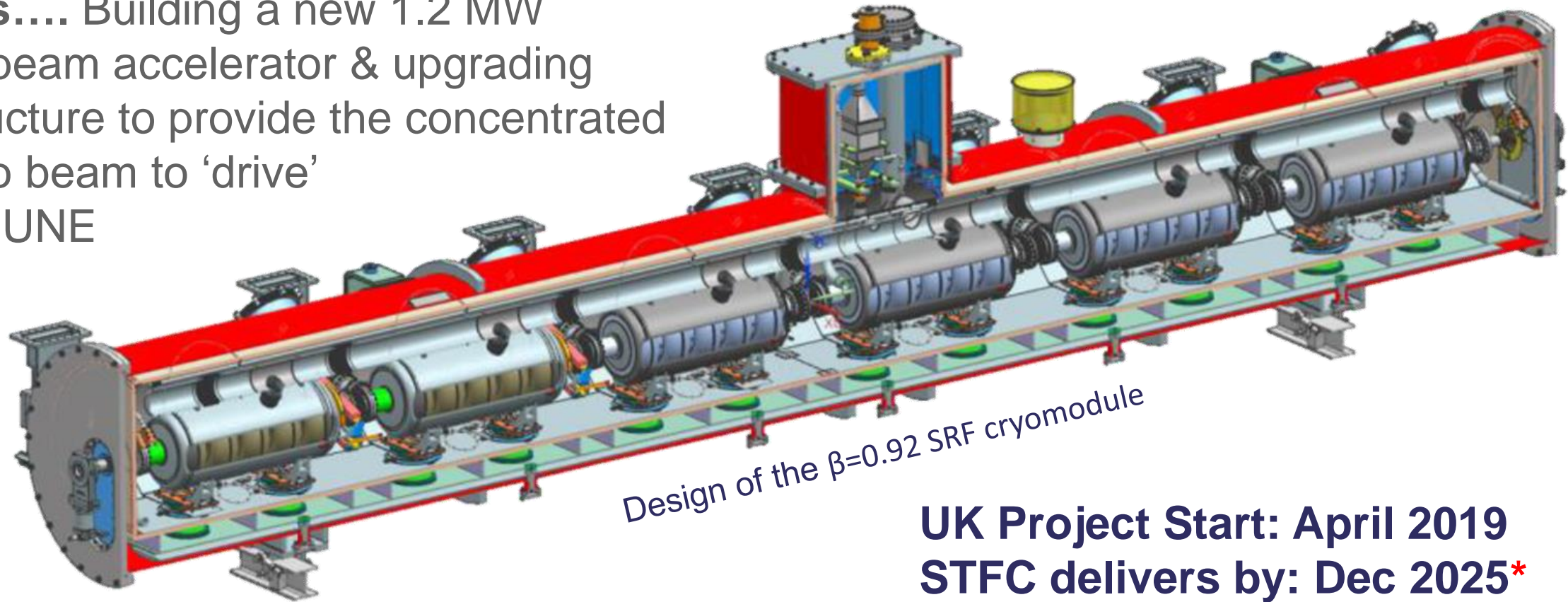
PIP-II Superconducting Linac



Project Goals

We are.... Working within an international collaboration to deliver 3 high beta superconducting RF cryomodules to FNAL.

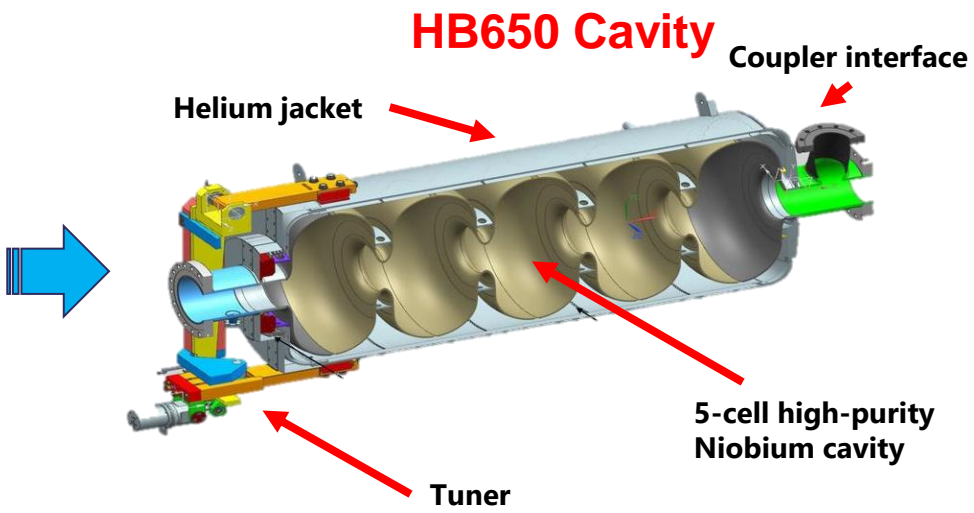
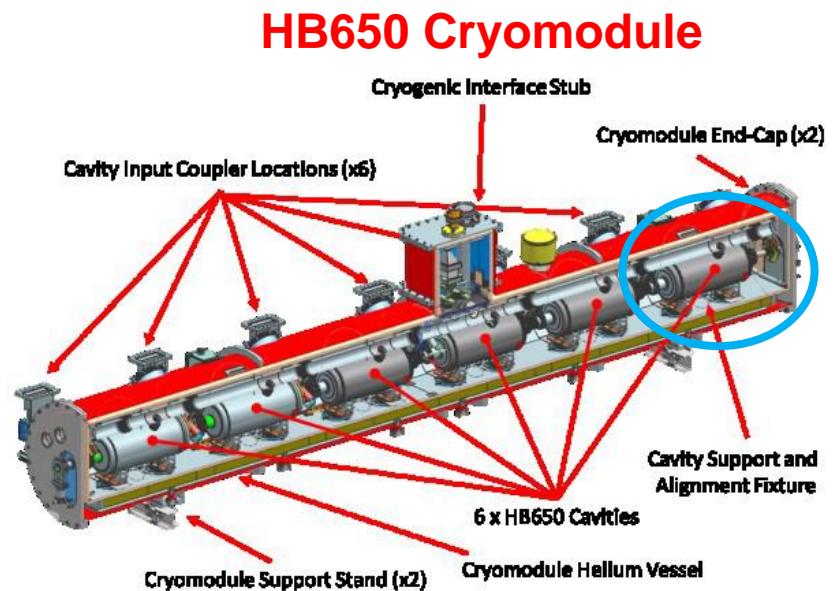
FNAL is.... Building a new 1.2 MW Proton beam accelerator & upgrading infrastructure to provide the concentrated Neutrino beam to 'drive' LBNF/DUNE



UK Project Start: April 2019
STFC delivers by: Dec 2025*

***CV-19 impact**

UK PIP-II Contribution



Cryomodule (CM)	PIP-II
Operating Temperature (K)	2
Number of Cavities	6
Energy Gain (MeV)	~110
Dynamic Load (W)	130
Static Load (W)	32
CM Length (m)	9.8
Number of Cryomodules	3

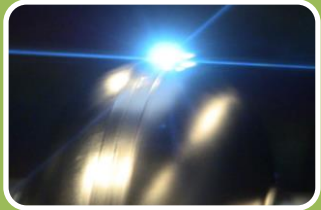
Cavity	PIP-II
Frequency (MHz)	650
Cavity Beta	0.92
Gradient (MV/m)	19
Quality Factor Qo	>3 x 10 ¹⁰ (N2 Doped)
Number of Cells	5
Cavity Dynamic Load (W)	<22
Cavity Length (m)	1.42
Number of Cavities	18 (+2)

Scope/Delivery Dates



WP5.1 SRF Infrastructure

- **Provision of all preparation, testing and assembly facilities.**
 - Extensively modify existing SRF facilities and provision of new cleanroom.
 - Implementation of new cryomodule vessel assembly fixtures.



WP5.2 UK Industry Development

- **Demonstration of UK PIP-II cavity demonstrator fabrication.**
 - Development of EBW processes for Nb material.
 - Provision of all SRF cavity fabrication facilities.



WP5.3 Cavity Qualification

- **Qualification of 18 (+2) x HB650 cavities to FNAL specifications.**
 - Procurement of Niobium material and cavity fabrication from industry.
 - Integration into testing infrastructure and validate.



WP5.4 Cryomodule Integration

- **Assembly of 3 x HB650 cryomodules to FNAL specifications.**
 - Prepare HB650 cavities and assemble cavity string in cleanroom.
 - Integrate cavity string into HB650 cryomodule vessel and acceptance test.
 - Safely transport integrated cryomodules to FNAL and acceptance test.



Signing ceremony: Mark Thomson (STFC-UKRI) and Nigel Lockyer (FNAL)
May 11th 2021.

STFC UKRI Deliverables	Acceptance Early Date
HB650 CM1	Jan-2025
HB650 CM2	Jul-2025
HB650 CM3	Dec-2025

Project Goals – Work Packages

WP1 – SRF Infrastructure

Mark Pendleton



WP2 – UK Industry Dev.

Anthony Gleeson



NUCLEAR AMRC



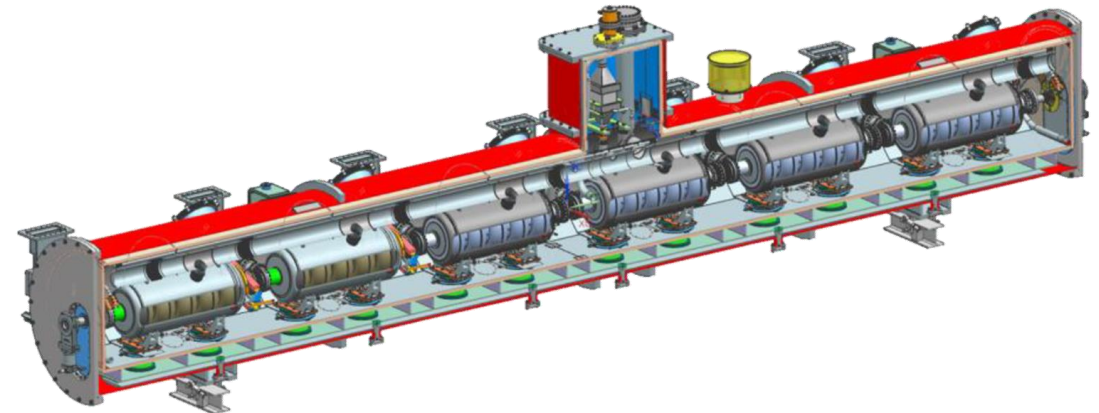
WP3 – Cavity Qualification

Anna Shabalina



WP4 – Cryomodule Integration

Shrikant Pattalwar



Milestones Achieved since Jan 22

WP	Description	PPD Date	Working Schedule Date (Actuals = A, Forecast = F)
FNAL	Final Design Review (FDR) for B.92 Cavities	Sep 21	April 2022 A
WP3	Production cavity manufacture tender released	Oct 21	April 2022 A
WP2	D-1 cavity manufactured by TWI	Oct 21	June 22 A
WP3	Niobium for 'production run' of cavities delivered	Oct 21	July 22 F
WP1	ISO4 Cleanroom tender released	Dec 21	Dec 21 A
WP 1	Cleanroom complete (full scope, not just initial contract)	Sep 22	July 22 F

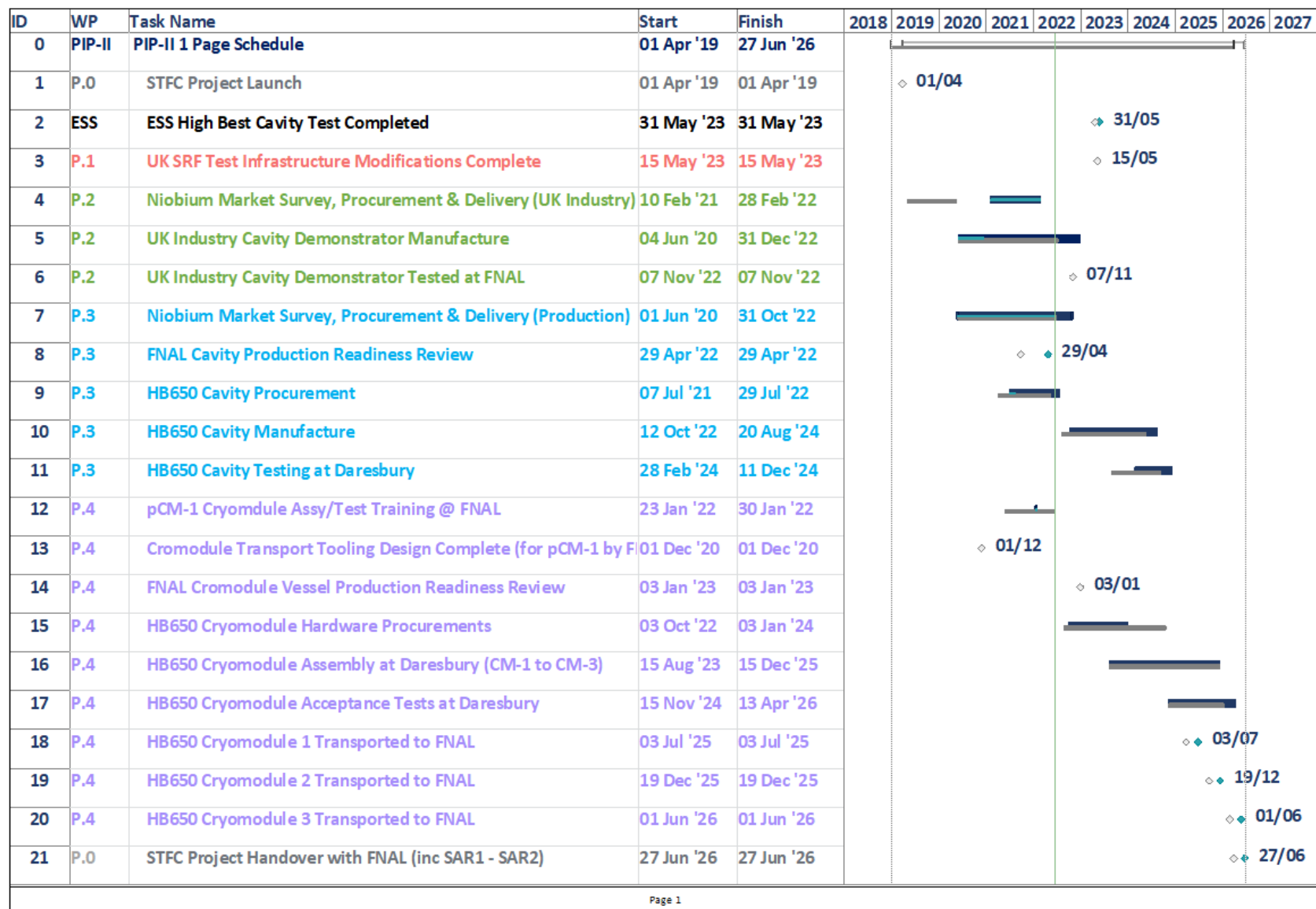


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Work Package Update

Project Management: WP0

PIP-II Cryomodule Delivery Plan



Grey bars = Jan 22 Plan
 Dark blue bars = Jun 22 Plan
 White diamonds = Jan 22 m/s
 Green diamonds = Jun 22 m/s

Key messages

Aggregate delay > 6 months

Primary drivers:

- Nb material quality (9-mo) – OTIC (China).
- Cavity Production Readiness Review (6-mo) - FNAL.



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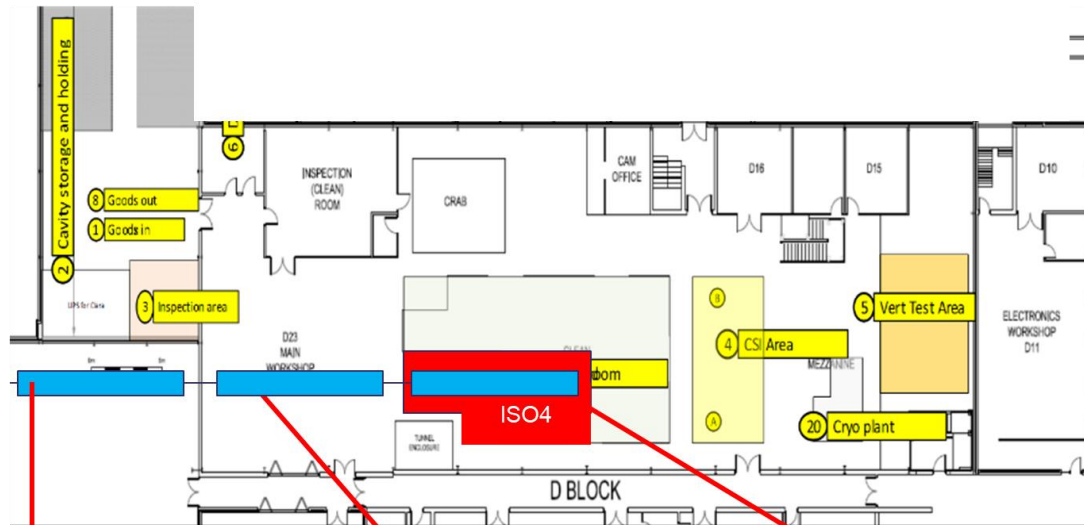
Work Package Update

Technical Workpackages: WP1 – 4

WP1 – PIP-II SRF Infrastructure

ISO4 Cleanroom – Cavity-string assembly

- Sudlows contracted to complete design, installation and commissioning of 14m x 5m ISO4 cleanroom.
- Expect to be completed Jul 22, final stage installation and commissioning underway.



Outer vessel integration



String to support & shields



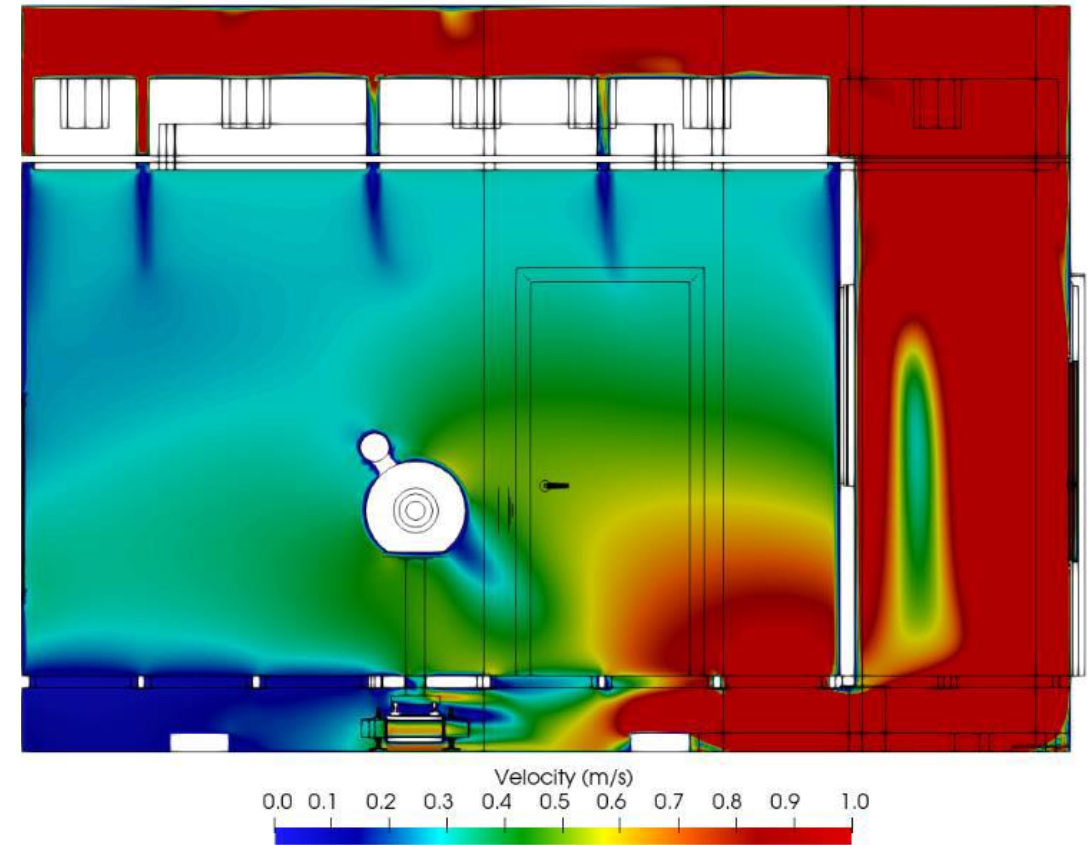
Cavity string assembly



WP1 – PIP-II SRF Infrastructure

ISO4 Cleanroom – Rail System

- Complete CFD model of all support arrangements for cavity string – underfloor rail system (and ‘lollipop’ stands).
- Complete civil works; install rail system; deep clean; fit fan filter units.
- Commission new facility, balance air flow between new & existing ESS cleanrooms – common air handling systems.

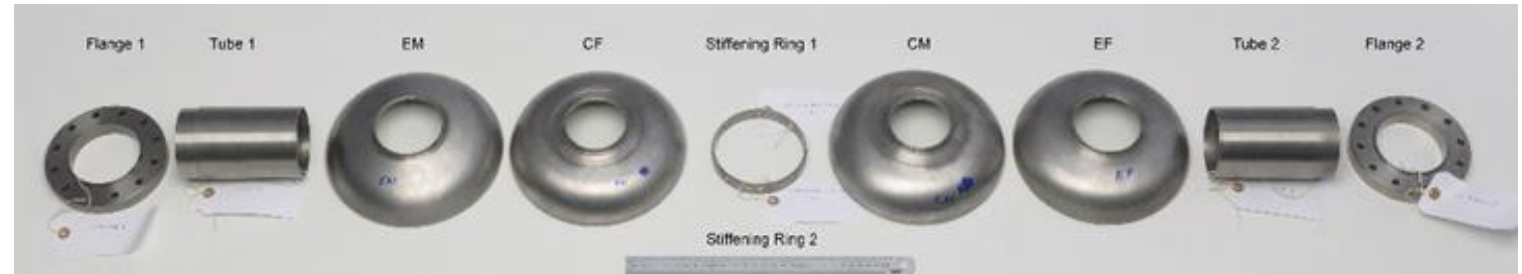


CFD confirms laminar flow maintained across cavity interfaces.

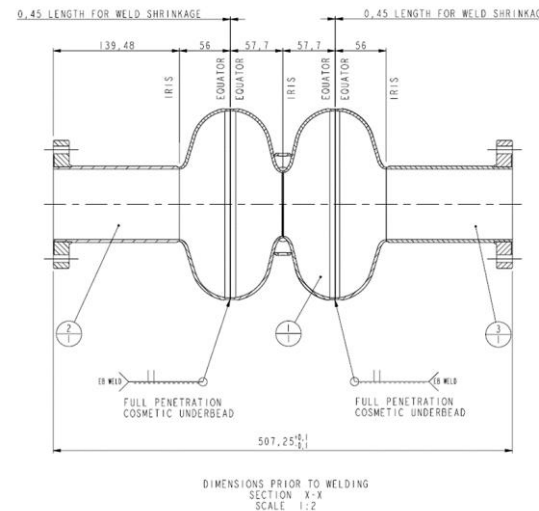
WP2 – UK Industry Development



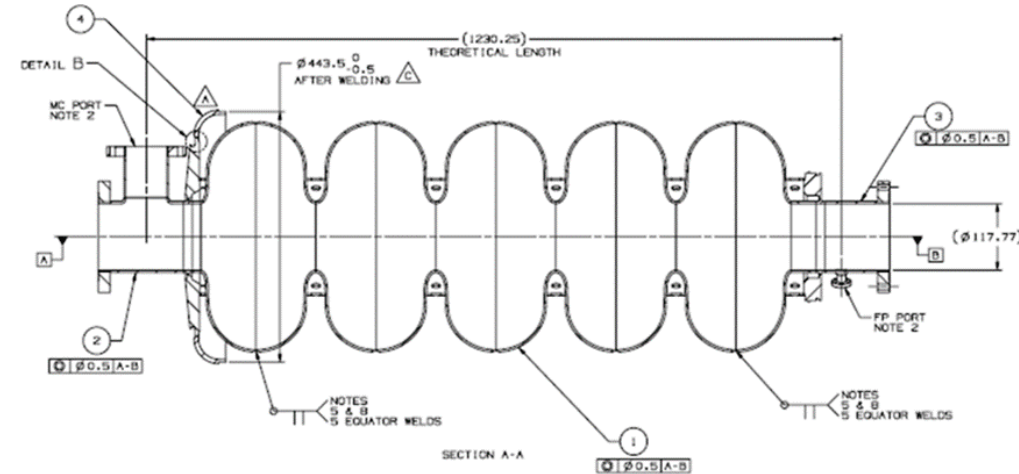
New Steigerwald
Electron Beam Welder installed and
commissioned at TWI (Dec 2020)



Components supplied to TWI to manufacture 2-cell test cavity



2-cell test cavity
Deliverable D1 (1.3 GHz)



5-cell 'Demonstrator' cavity
Deliverable D2 (650 MHz)

WP2 – UK Industry Development – D1 Cavity

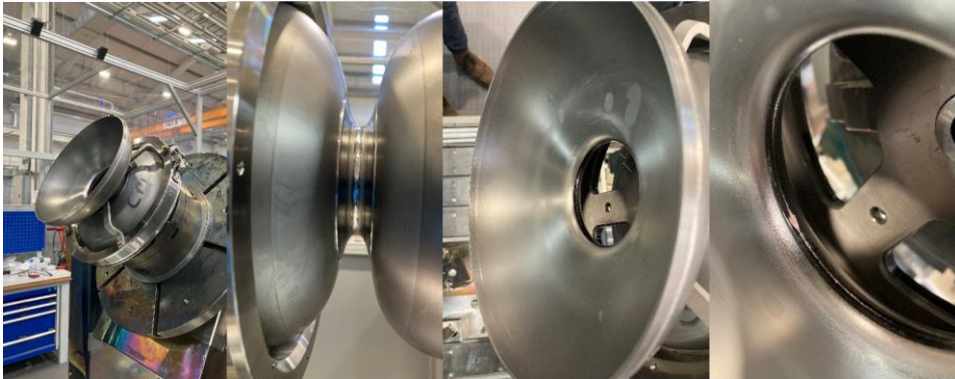
D1 Tooling

- Tooling design for D1 completed by NAMRC.
- D1 tooling manufacture completed.

Cavity Manufacture

- Cavity half cells (Cu) pressed by SEI.
- Cavity components prepared and EBW by TWI.

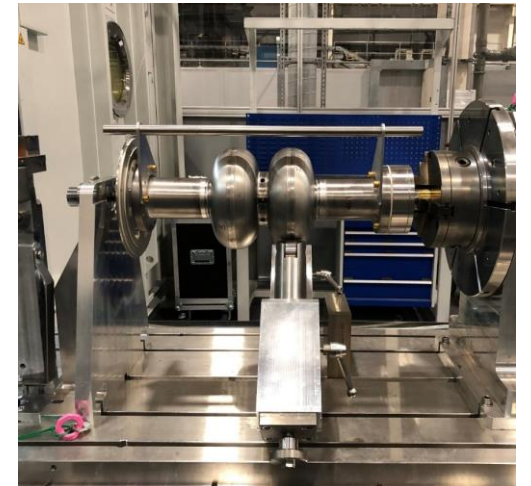
Dumbbell Welding



End-Group Welding



RF Measurements and Assembly Prior to Welding



WP2 – UK Industry Development – D1 Cavity

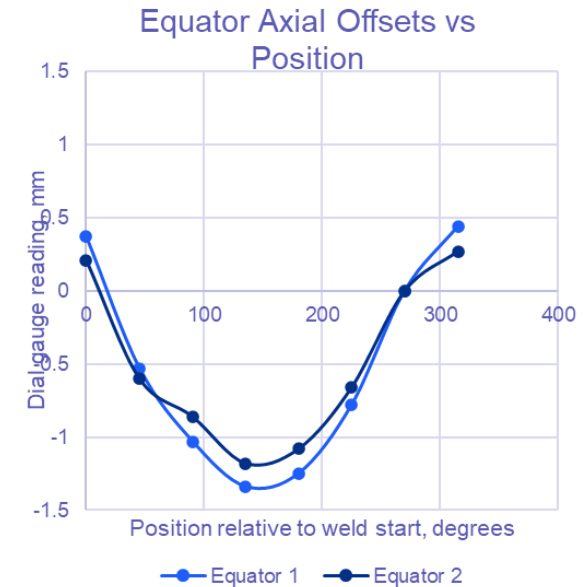
D1 Stiffening Ring

- Dimensional issues with stiffening ring strips required remanufacture.



D1 Post-EBW Checks

- Digital dial gauge use to record equator run-out vs angular position.
- Equator 1 and Equator 2 both tested.



Total length:

- Theoretical - 506.35mm
- Measured - 501.24mm

Flange face parallelism:

- Measured 0.66° off axis
- $\sim 1.7\text{mm}$ across the full flange

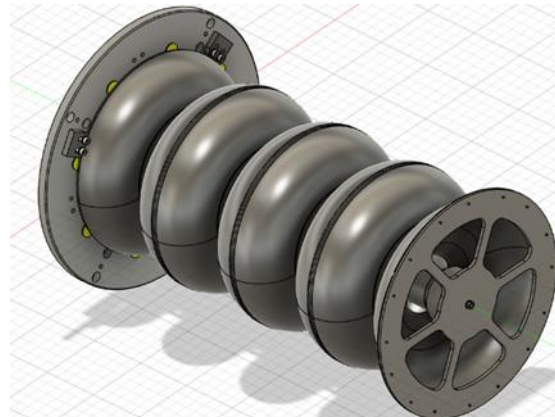
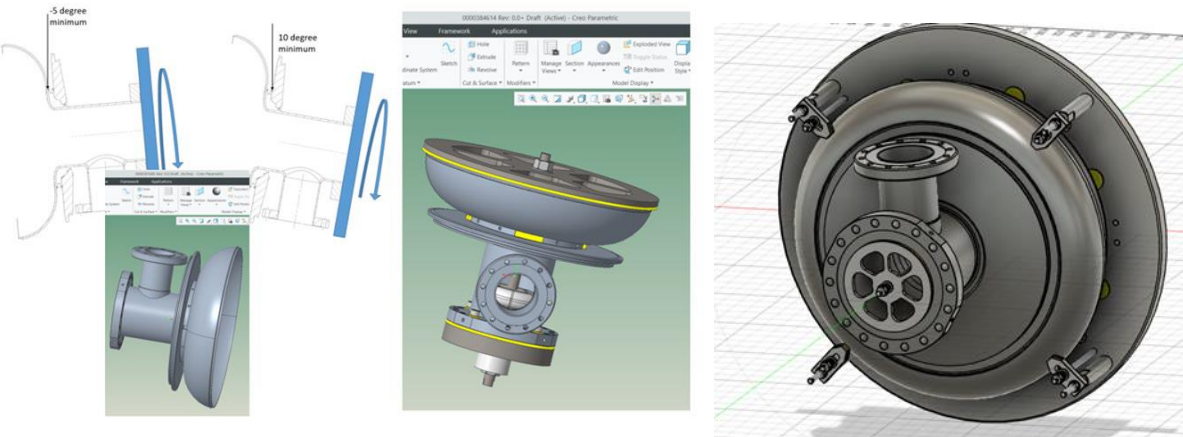
**Not expected to be problematic for RF testing
– ready to ship to FNAL for N2-doping & tests.**



WP2 – UK Industry Development – D2 Cavity

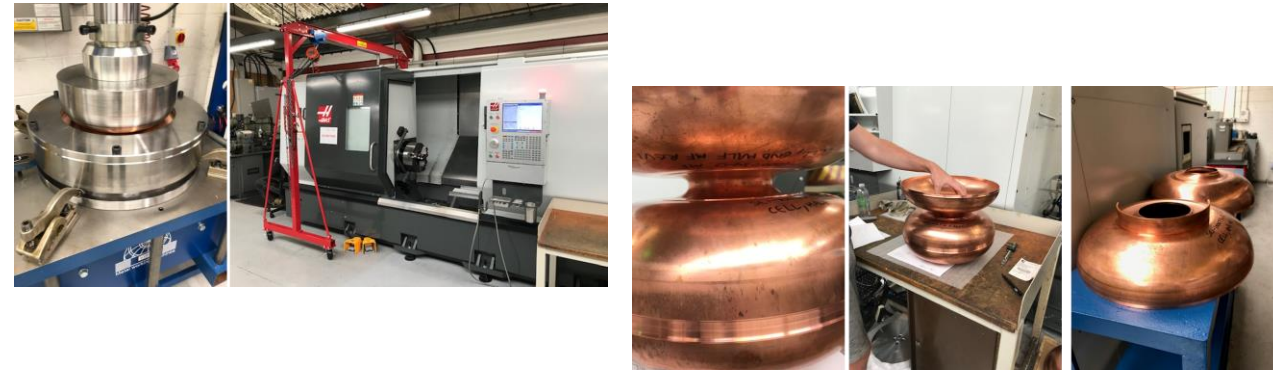
D2 Tooling

- Tooling design for D2 completed by NAMRC.
- D2 tooling manufacture completed.



D2 Cavity Manufacture

- Cavity half cells (Cu) pressed by SEI.
- Dimensional conformity (CMM) checks completed – ready to start Nb sheet forming.

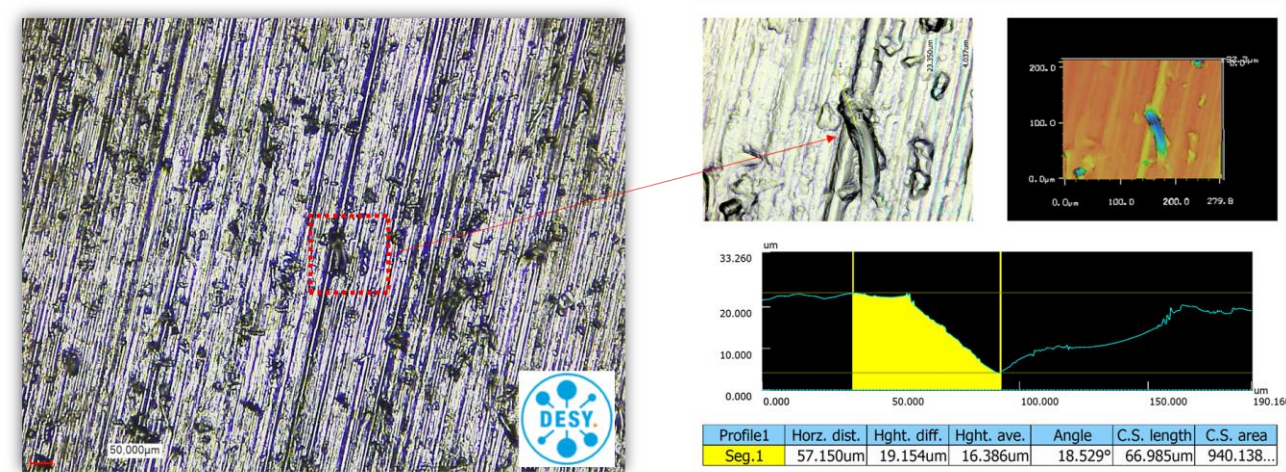


- TWI still do not yet have the required Nb-component etch facility – extensively delayed.
- **TWI missed opportunity to bid for cavity production - tender launched April 22!**
- Intention now to have D2 manufactured to include in cryomodule integration.
- **TWI to complete D2 and integrate Titanium cavity helium jacket manufacture.**

WP3 - PIP-II Cavity Qualification

Production Niobium Procurement

- Surface quality issues identified for disc material during initial inspection at DESY (Sept 21).
- At least 10 – 30 μm surface defects/holes (depth) for all sheets (>250 discs).



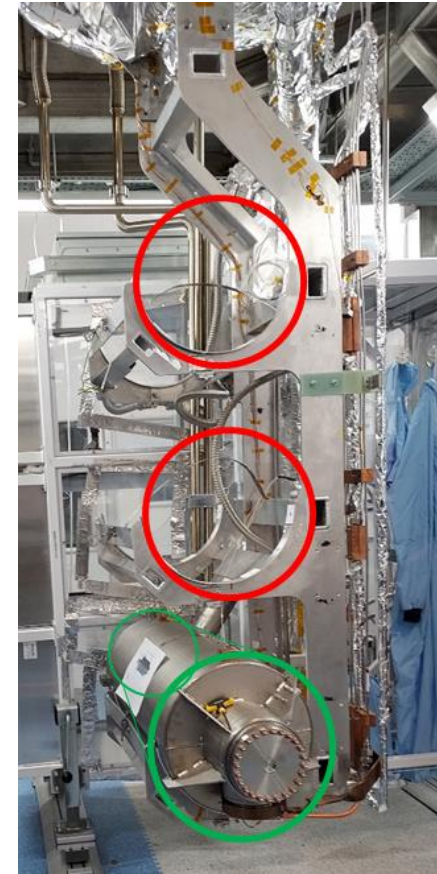
- OTIC solutions verified by ECS at DESY:
 - 90% success rate for repair - sheets within thickness tolerance.
 - 75% success rate for remanufacture.
 - Only 3/187 sheets unrecoverable.
- **First batch of material expected in July 22**

Fast Cooldown for High Qo

- Fast cool-down from 45 - 5K at 20K/min to expel the magnetic field trapped in the cavity - **10x faster than for ESS!**
- Modelling suggests cooling 3 x 650MHz cavities has too much heat load for the cryoplant - propose to test only one cavity per cold test.
- Additional gas storage capacity being implemented.
- Plan to validate with a single ESS cavity to verify capability.

This test must not interfere with ESS project completion.

Still awaiting opportunity for testing!



WP4 – Cryomodule Integration

Cryomodule Transport Frame

- STFC designed frame and completed Final Design Review (FDR) in Sept 20.

Frame Validation Methodology

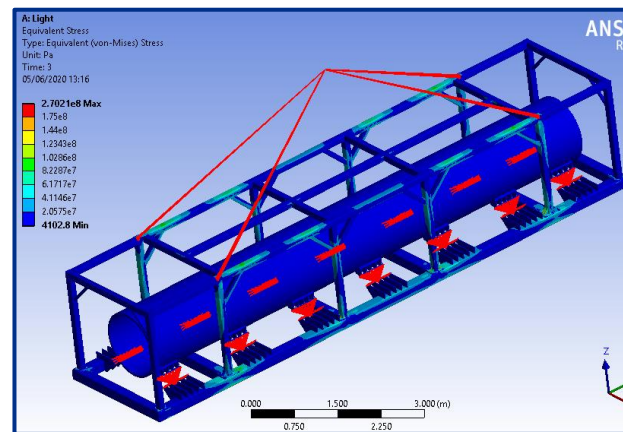
STFC frame manufactured by FNAL for use with the HB650 prototype cryomodule (pCM):

- pCM will be operationally tested at FNAL – end 2022 (delayed by 6-months)
- pCM to ship to STFC, provisional acceptance tests – visual, mechanical, RF and vacuum.
- pCM will ship back to FNAL – retested to verify its operational performance.

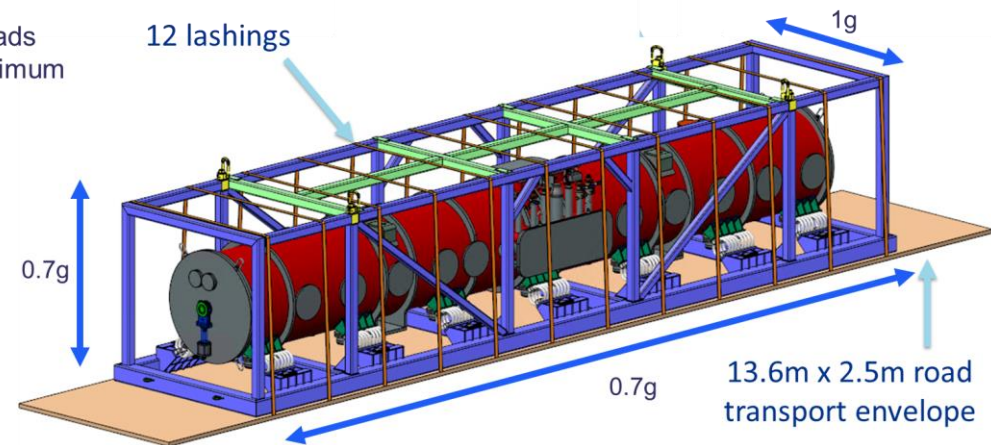
First frame tests performed at FNAL in Apr22, exceeded load/stress verification by factor of 2!



32-tonne load test @ FNAL – Jan 22



BS EN 12195-1:2010 loads applied (combined) Maximum stress of 101MPa



BS EN 12640:2019 load securing satisfied
12 lashings at 25.3kN tension



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Conclusions

Conclusions

- **Extensive delays impacting UK PIP-II delivery project:**
 - Nb material quality non-conformance with OTIC Ningxia (China).
 - Production cavity PRR documentation from FNAL.
 - Late completion of D2 and inability for TWI to bid into cavity production tender.
 - Unavailability of Nb-component etch facility at TWI for D2 cavity.
- **Significant successes however achieved:**
 - New ISO-4 cleanroom installation almost complete **on-time and within budget.**
 - D1 cavity manufactured by TWI, SEI and NAMRC – **UK First!**
 - PIP-II production cavity **tender launched (and now closed).**
 - Cryomodule transport frame manufactured and **first tests successfully completed** at FNAL.
- **Next stage planning (6-months):**
 - Cavity coupler and tuner Final Design Reviews.
 - First HB650 cryomodule sub-system FDRs.
 - Significant procurement exercises anticipated this year.



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Thank you

Acknowledgements

WP0 Kieran Cheetham
WP1 Mark Pendleton
WP2 Anthony Gleeson
WP3 Alan Wheelhouse
WP4 Shrikant Pattalwar
Mitchell Kane



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