

# Status of RFD Cryomodules

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TRIUMF Hi-Lumi Technical Coordinator

Oct. 7, 2024

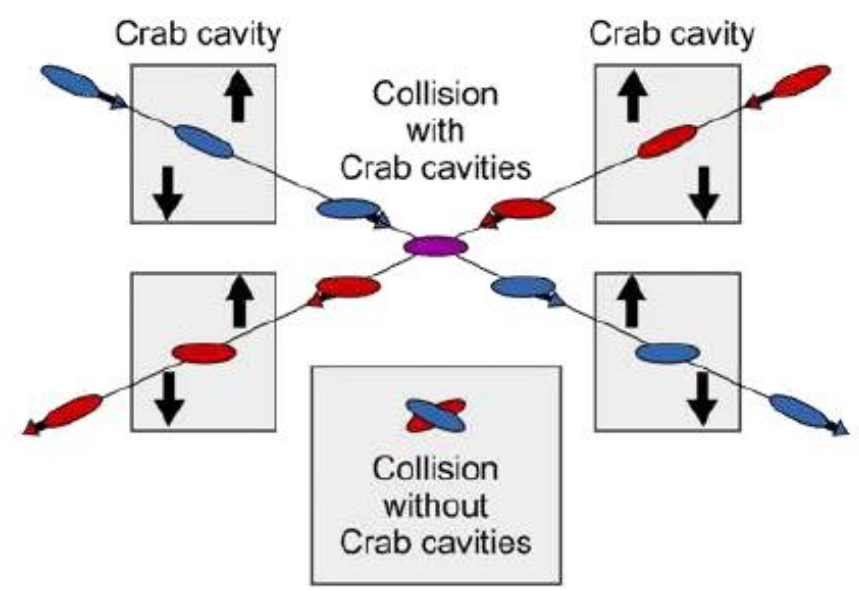
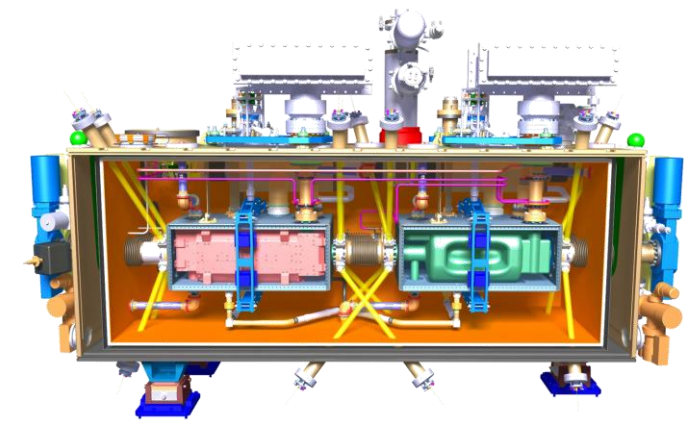
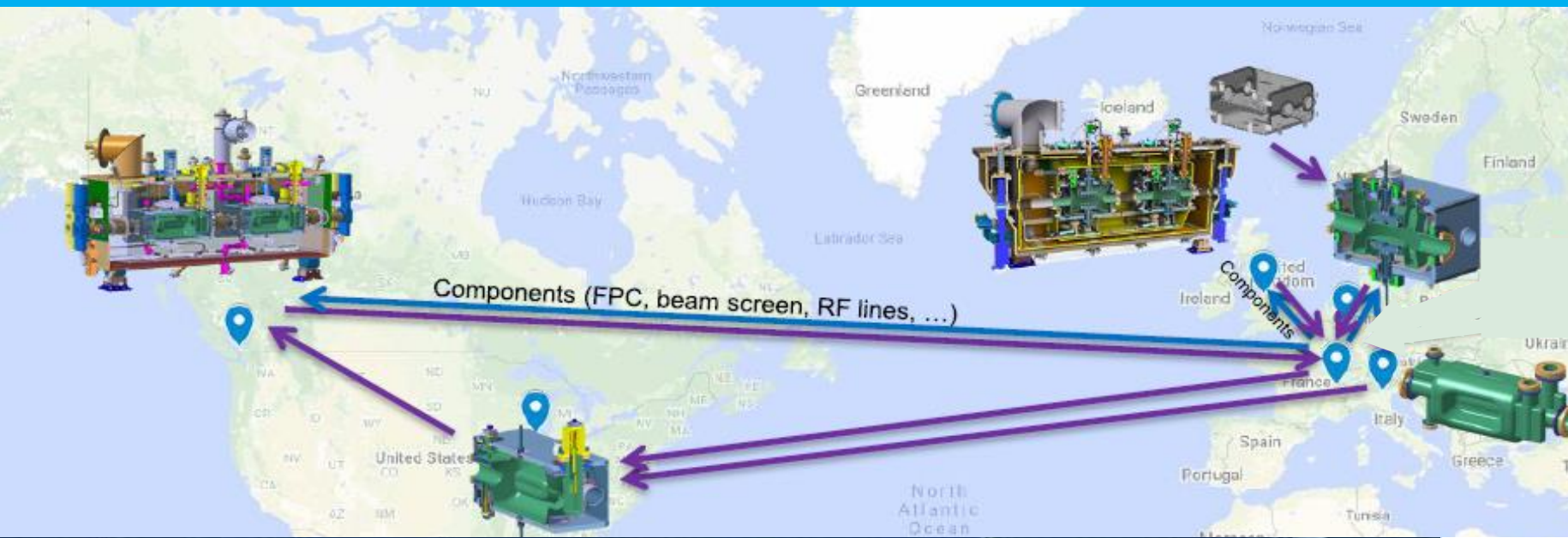


TRIUMF is  
Canada's  
particle  
accelerator  
centre



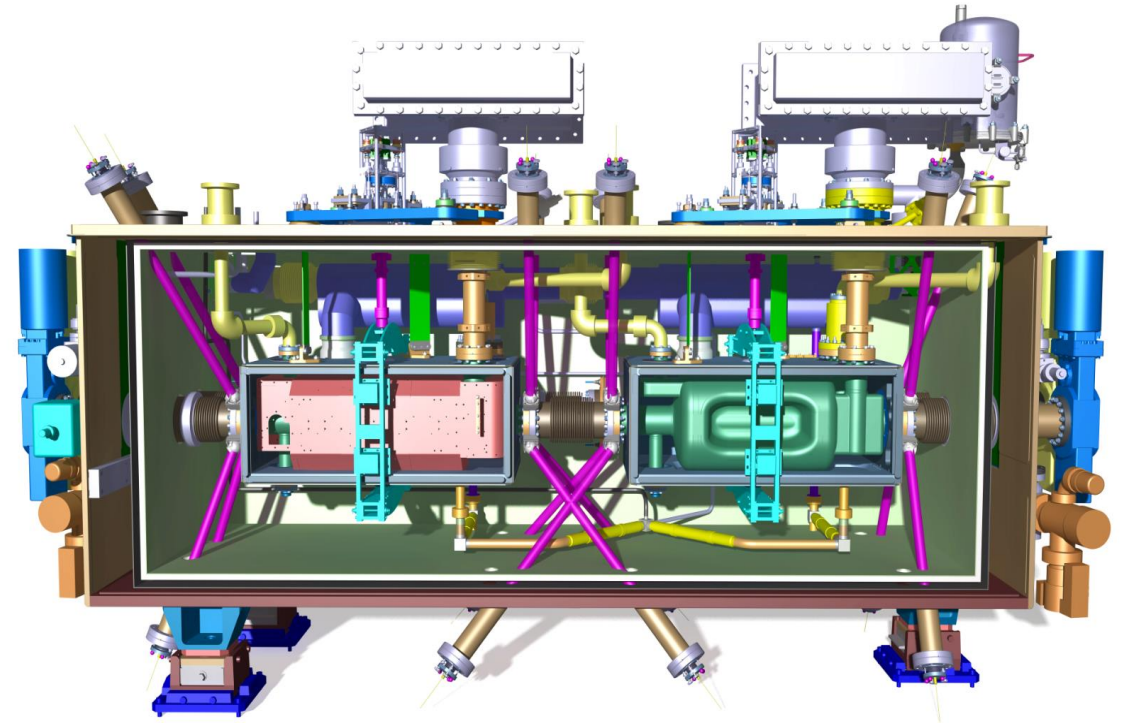
# Scope and constraints

# TRIUMF is part of global collaboration (CERN, USA, UK) that will deliver RFD Crab Cavity modules as a Canadian contribution to Hi-Lumi

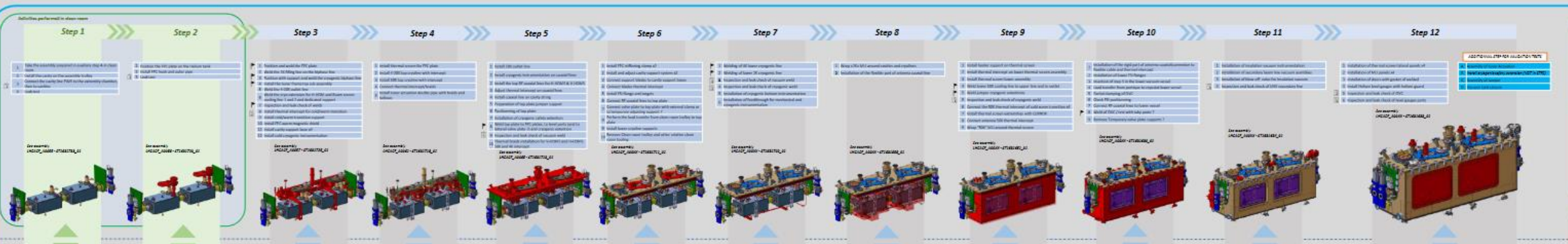


# Scope of Canadian Contribution

- TRIUMF to work with CERN and UK colleagues to develop RFD cryomodule design and tooling
- TRIUMF to receive and re-qualify 10 dressed RFD resonators (US-AUP scope)
- TRIUMF to install the fundamental power coupler (CERN scope) and to assemble each pair of RFDs into five hermetic strings
- TRIUMF to assemble hermetic strings into five cryomodules and qualify performance
- TRIUMF to package and ship cryomodules to CERN



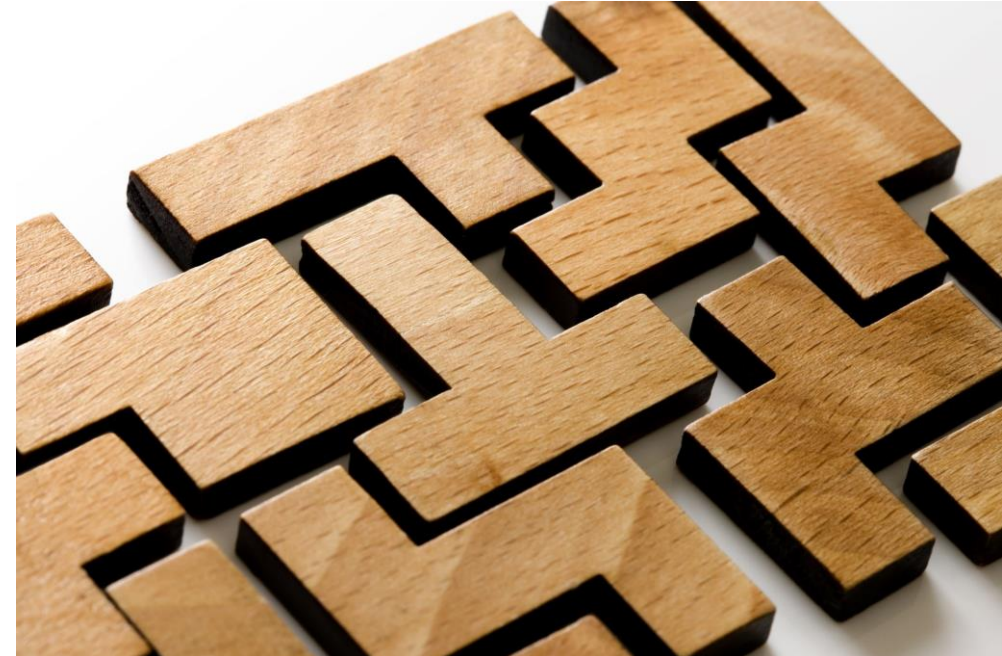
# The RF Dipole Cryomodule- Step by step



<b>Cavity equipped</b> IAC12P02011-0101 - Pre-assembly stage IAC12P02011-0102 - Dressing cavity	<b>PPC Assembly with outer pipe &amp; bellows</b> IAC12P02011-0103 - PPC assembly	<b>Upper cryoline</b> IAC12P02011-0104 - Upper cryoline	<b>PPC thermal screen</b> IAC12P02011-0105 - Thermal screen IAC12P02011-0106 - Thermal screen IAC12P02011-0107 - Thermal screen	<b>30K outlet line</b> IAC12P02011-0108 - 30K outlet line IAC12P02011-0109 - 30K outlet line IAC12P02011-0110 - 30K outlet line	<b>PPC plate clamp</b> IAC12P02011-0111 - PPC plate clamp	<b>Beam screen cooling line</b> IAC12P02011-0112 - Beam screen cooling line IAC12P02011-0113 - Beam screen cooling line IAC12P02011-0114 - Beam screen cooling line	<b>MLU 2K</b> IAC12P02011-0115 - MLU 2K IAC12P02011-0116 - MLU 2K IAC12P02011-0117 - MLU 2K	<b>Internal cryo support</b> IAC12P02011-0118 - Internal cryo support IAC12P02011-0119 - Internal cryo support IAC12P02011-0120 - Internal cryo support	<b>Vacuum vessel</b> IAC12P02011-0121 - Vacuum vessel IAC12P02011-0122 - Vacuum vessel IAC12P02011-0123 - Vacuum vessel	<b>Extremely vacuum insul.</b> IAC12P02011-0124 - Extremely vacuum insul. IAC12P02011-0125 - Extremely vacuum insul.	<b>Doors</b> IAC12P02011-0126 - Doors IAC12P02011-0127 - Doors IAC12P02011-0128 - Doors	<b>Tuner installation</b> IAC12P02011-0129 - Tuner installation IAC12P02011-0130 - Tuner installation		
<b>LMV shielded bellows</b> IAC12P02011-0131 - LMV shielded bellows IAC12P02011-0132 - LMV shielded bellows IAC12P02011-0133 - LMV shielded bellows	<b>PPC plate for OVC</b> IAC12P02011-0134 - PPC plate for OVC	<b>2K filling line</b> IAC12P02011-0135 - 2K filling line IAC12P02011-0136 - 2K filling line	<b>PPC MLU</b> IAC12P02011-0137 - PPC MLU IAC12P02011-0138 - PPC MLU IAC12P02011-0139 - PPC MLU	<b>Cryo instrumentation 2/4</b> IAC12P02011-0140 - Cryo instrumentation 2/4 IAC12P02011-0141 - Cryo instrumentation 2/4 IAC12P02011-0142 - Cryo instrumentation 2/4	<b>Cavity support</b> IAC12P02011-0143 - Cavity support IAC12P02011-0144 - Cavity support IAC12P02011-0145 - Cavity support	<b>Lower cryogenic line</b> IAC12P02011-0146 - Lower cryogenic line IAC12P02011-0147 - Lower cryogenic line IAC12P02011-0148 - Lower cryogenic line	<b>Antennas - RF lines 1/2 Cable installation</b> IAC12P02011-0149 - Antennas - RF lines 1/2 IAC12P02011-0150 - Antennas - RF lines 1/2 IAC12P02011-0151 - Antennas - RF lines 1/2	<b>Thermostat pool</b> IAC12P02011-0152 - Thermostat pool IAC12P02011-0153 - Thermostat pool	<b>Thermal intercepts</b> IAC12P02011-0154 - Thermal intercepts IAC12P02011-0155 - Thermal intercepts IAC12P02011-0156 - Thermal intercepts	<b>Thermal intercepts</b> IAC12P02011-0157 - Thermal intercepts IAC12P02011-0158 - Thermal intercepts IAC12P02011-0159 - Thermal intercepts	<b>PSI flanges with clamps</b> IAC12P02011-0160 - PSI flanges with clamps IAC12P02011-0161 - PSI flanges with clamps IAC12P02011-0162 - PSI flanges with clamps	<b>Cryo instrumentation 4/4</b> IAC12P02011-0163 - Cryo instrumentation 4/4 IAC12P02011-0164 - Cryo instrumentation 4/4 IAC12P02011-0165 - Cryo instrumentation 4/4	<b>Level gauge and helium guard</b> IAC12P02011-0166 - Level gauge and helium guard IAC12P02011-0167 - Level gauge and helium guard IAC12P02011-0168 - Level gauge and helium guard	<b>Instrumentation Boxes</b> IAC12P02011-0169 - Instrumentation Boxes IAC12P02011-0170 - Instrumentation Boxes
<b>Extremely vacuum insul.</b> IAC12P02011-0171 - Extremely vacuum insul. IAC12P02011-0172 - Extremely vacuum insul.	<b>Valve plate</b> IAC12P02011-0173 - Valve plate	<b>4-20K cooling line</b> IAC12P02011-0174 - 4-20K cooling line IAC12P02011-0175 - 4-20K cooling line	<b>4K upper line</b> IAC12P02011-0176 - 4K upper line IAC12P02011-0177 - 4K upper line	<b>hDMS - RF central lines &amp; intercepts</b> IAC12P02011-0178 - hDMS - RF central lines & intercepts IAC12P02011-0179 - hDMS - RF central lines & intercepts IAC12P02011-0180 - hDMS - RF central lines & intercepts	<b>External clamp</b> IAC12P02011-0181 - External clamp IAC12P02011-0182 - External clamp IAC12P02011-0183 - External clamp	<b>Cryo instrumentation 3/4</b> IAC12P02011-0184 - Cryo instrumentation 3/4 IAC12P02011-0185 - Cryo instrumentation 3/4 IAC12P02011-0186 - Cryo instrumentation 3/4	<b>Thermostat pool</b> IAC12P02011-0187 - Thermostat pool IAC12P02011-0188 - Thermostat pool	<b>Magnetic shield and panels</b> IAC12P02011-0189 - Magnetic shield and panels IAC12P02011-0190 - Magnetic shield and panels	<b>External clamp</b> IAC12P02011-0191 - External clamp IAC12P02011-0192 - External clamp IAC12P02011-0193 - External clamp	<b>Valve plate clamp</b> IAC12P02011-0194 - Valve plate clamp IAC12P02011-0195 - Valve plate clamp	<b>Internal instrum. feedthroughs</b> IAC12P02011-0196 - Internal instrum. feedthroughs IAC12P02011-0197 - Internal instrum. feedthroughs IAC12P02011-0198 - Internal instrum. feedthroughs	<b>MLU 20K</b> IAC12P02011-0199 - MLU 20K IAC12P02011-0200 - MLU 20K	<b>External heaters and sensors</b> IAC12P02011-0201 - External heaters and sensors IAC12P02011-0202 - External heaters and sensors IAC12P02011-0203 - External heaters and sensors	<b>TO BE UPDATED</b>
<b>Internal support</b> IAC12P02011-0204 - Internal support IAC12P02011-0205 - Internal support IAC12P02011-0206 - Internal support	<b>PPC Magnetic shield</b> IAC12P02011-0207 - PPC Magnetic shield IAC12P02011-0208 - PPC Magnetic shield IAC12P02011-0209 - PPC Magnetic shield	<b>PPC thermal links</b> IAC12P02011-0210 - PPC thermal links IAC12P02011-0211 - PPC thermal links IAC12P02011-0212 - PPC thermal links	<b>Tuner visible pipe &amp; intercepts</b> IAC12P02011-0213 - Tuner visible pipe & intercepts IAC12P02011-0214 - Tuner visible pipe & intercepts IAC12P02011-0215 - Tuner visible pipe & intercepts	<b>Jumpers assembly</b> IAC12P02011-0216 - Jumper assembly IAC12P02011-0217 - Jumper assembly IAC12P02011-0218 - Jumper assembly	<b>Beam screen cooling line</b> IAC12P02011-0219 - Beam screen cooling line IAC12P02011-0220 - Beam screen cooling line IAC12P02011-0221 - Beam screen cooling line	<b>MLU 2K</b> IAC12P02011-0222 - MLU 2K IAC12P02011-0223 - MLU 2K IAC12P02011-0224 - MLU 2K	<b>Lower cooling line 30K</b> IAC12P02011-0225 - Lower cooling line 30K IAC12P02011-0226 - Lower cooling line 30K IAC12P02011-0227 - Lower cooling line 30K	<b>PSI targets</b> IAC12P02011-0228 - PSI targets IAC12P02011-0229 - PSI targets IAC12P02011-0230 - PSI targets	<b>Valve plate clamp</b> IAC12P02011-0231 - Valve plate clamp IAC12P02011-0232 - Valve plate clamp IAC12P02011-0233 - Valve plate clamp	<b>TO BE UPDATED</b>	<b>TO BE UPDATED</b>	<b>TO BE UPDATED</b>	<b>TO BE UPDATED</b>	

# Project Strategy

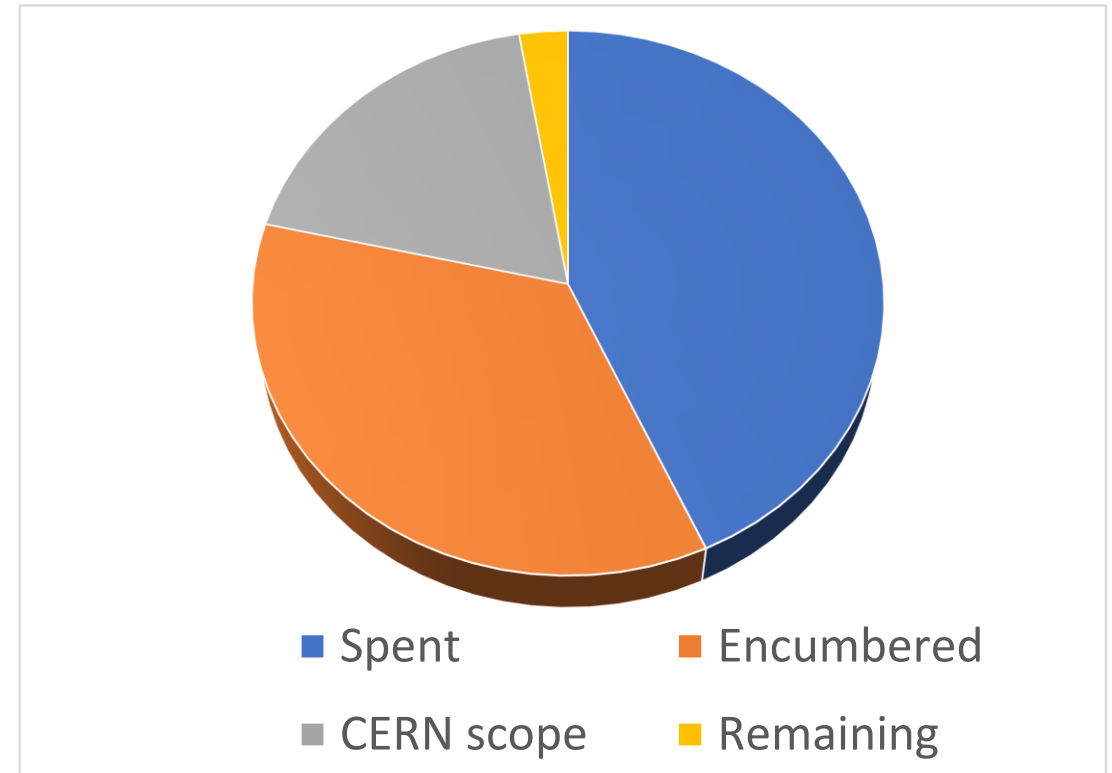
- The project strategy calls for procurement of parts for a single cryomodule, TCM0, followed by procurement of parts for the production series TCM1-4
- Project slippages due to Covid and other forces vs. boundary conditions on project funds are having an impact on this strategy
  - Shifting timelines for
    - TCM0 cavities from AUP
    - Released drawings, deliverables and parts lists from CERN
  - Fixed timeline for spending the funds
- The present strategy has been to procure series components as soon as drawings are released and strategically assign some scope to CERN in order to spend \$\$ within fixed timeline



# Funding and priorities

- Due to the nature of the funding agreement ALL funds for the project must be spent and all parts received (to trigger payment) before April 2025
- ✓ Over 5M\$ has been committed over the last year - TRIUMF has presently spent or committed 97% of the funds
- Present risks
  - Over 50% of funds are encumbered including 19% from CERN that need delivery to TRIUMF before April 2025
  - Some drawing packages and procured parts lists are still not released

Spent	Encumbered	CERN scope	Remaining
<b>\$4,328,342</b>	<b>\$3,531,564</b>	<b>\$1,873,701</b>	<b>\$266,393</b>
43.3%	35.3%	18.7%	2.7%





# Cryomodule Assembly Boundary Conditions

- CM string assembly requires cavities from AUP, FPCs and beamline assemblies from CERN – first articles are required to assemble TCM0 and TCM1
- TRIUMF also requires delivery of CM parts from CERN for both *in scope* articles and *added scope* articles (at least for first units):
- TRIUMF site planning calls for a long shutdown in 2026 to help concentrate effort on the ARIEL project – all cavity qualification tests will be completed but a slowdown in Hi-Lumi CM assembly is foreseen



<b>AUP Delivery Projection</b>		
<b>Cavity Pair</b>	<b>Module</b>	<b>Delivery</b>
Prototype	TCM0	Feb 2025
Cavities 1 and 2	TCM1	May 2025
Cavities 3 and 4	TCM2	Jun 2025
Cavities 5 and 6	TCM3	Jul 2024
Cavities 7 and 8	TCM4	Aug 2025
Cavities 9 and 10	TCM5	Sep 2025



# Recent Milestones

## Recent milestones

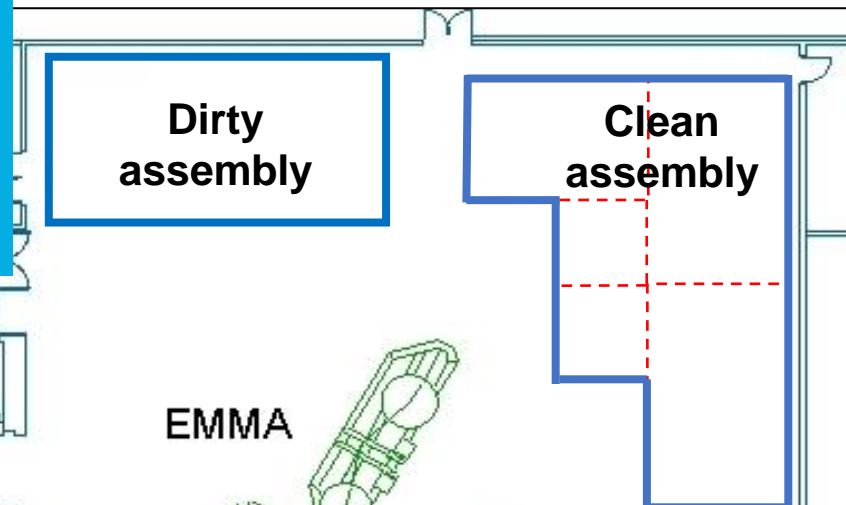
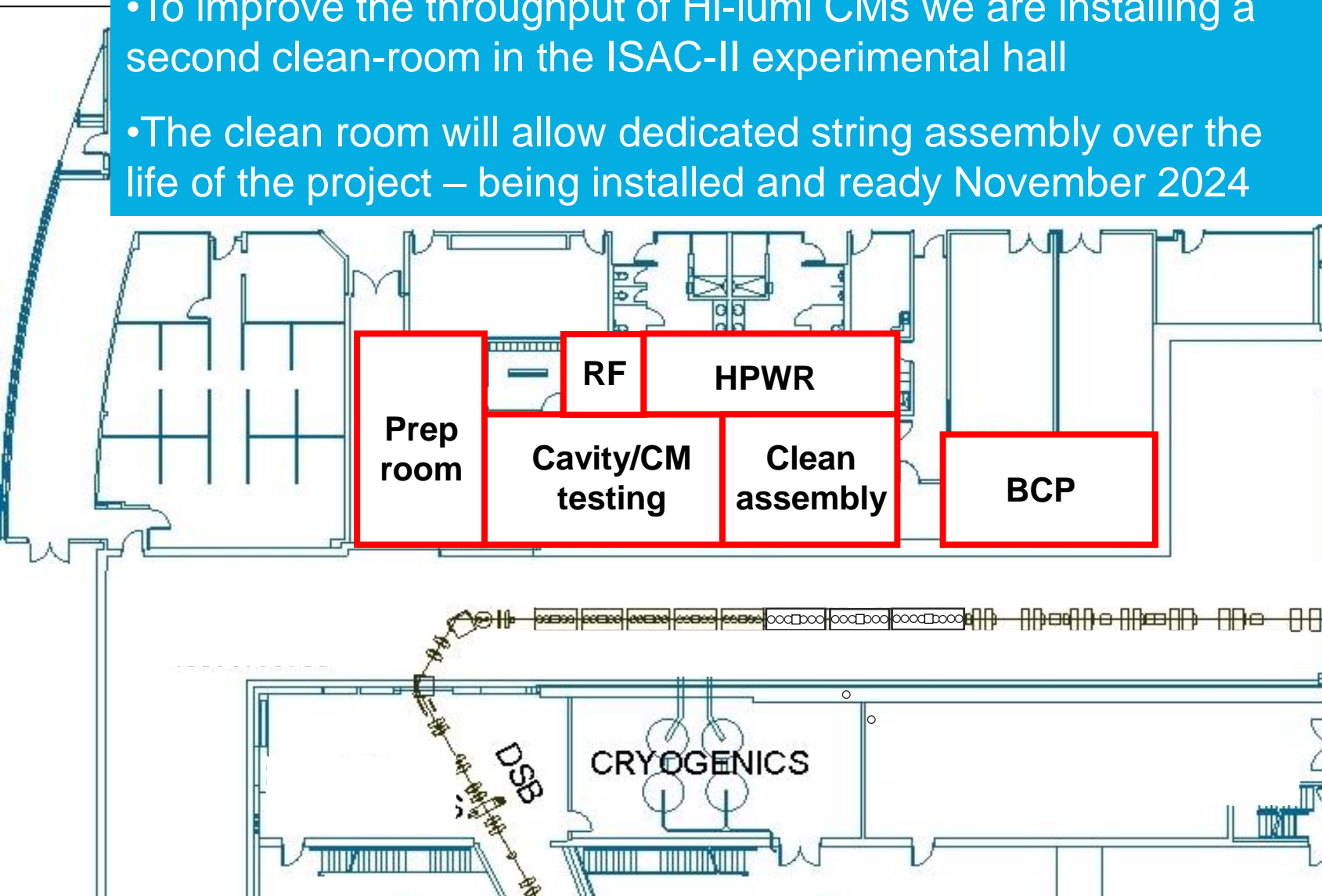
<b>Milestone</b>	<b>Application</b>	<b>Achieved</b>
Clean room contract issued	Infrastructure	Sep 2023
OVC material order received	TCM1-5	Feb. 2024
OVC fabrication order issued	TCM1-5	Feb 2024
MLI contract issued	TCM1-5	Mar. 2024
Dummy cavity received	Infrastructure	June 2024
Mu-metal received	TCM1-3	Aug. 2024
Top assembly frame received	Infrastructure	Aug. 2024
Tuner frame/flexures fabrication issued	TCM1-5	Sept. 2024
Thermal shield fabrication issued	TCM1-5	Sept. 2024
String assembly cart complete	Infrastructure	Sept. 2024

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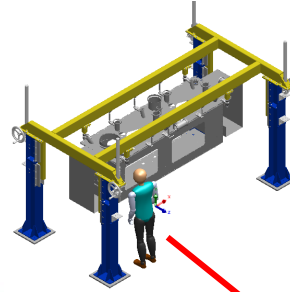
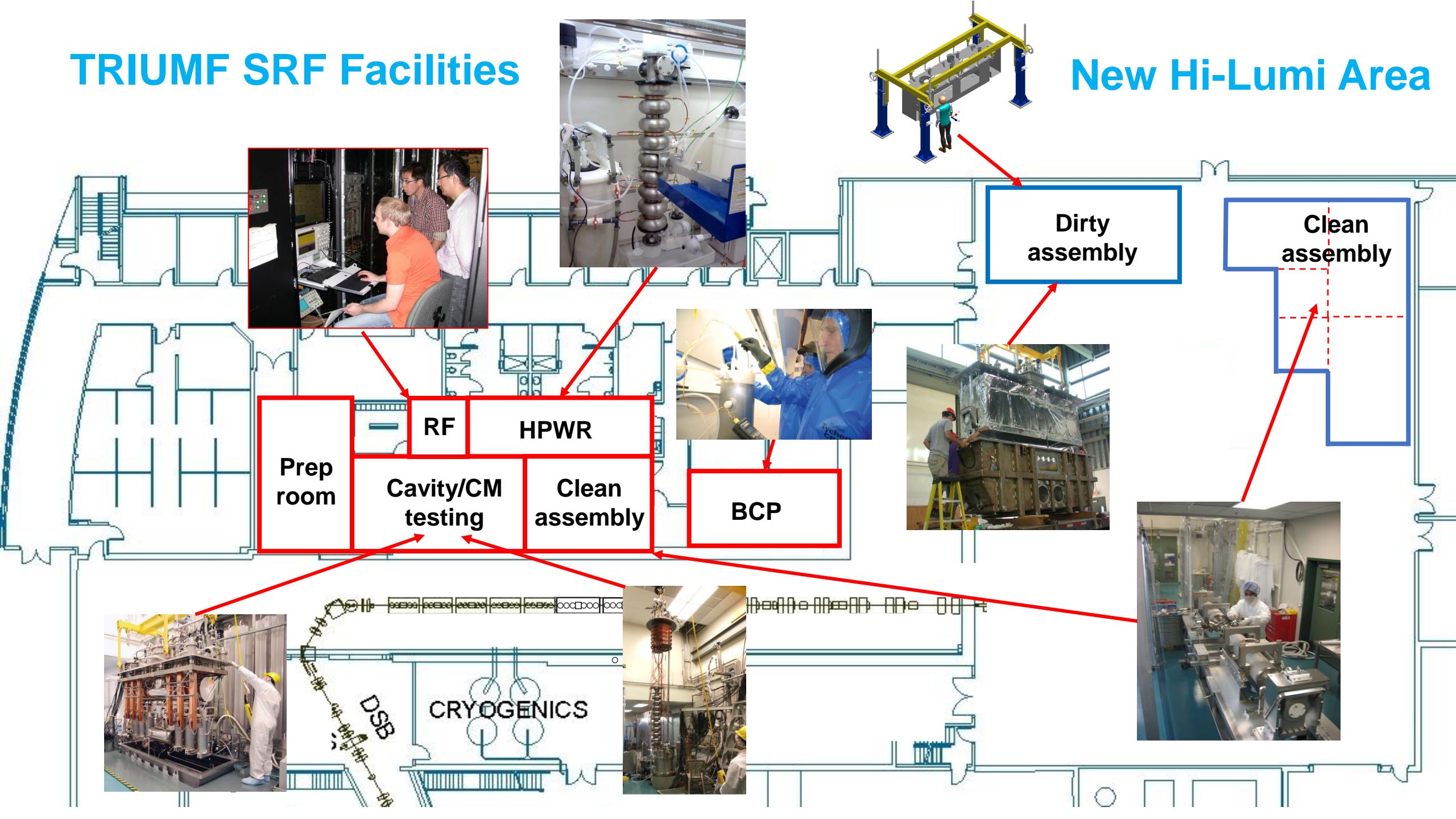
# TRIUMF SRF Facilities – Hi-Lumi Upgrade

- To improve the throughput of Hi-lumi CMs we are installing a second clean-room in the ISAC-II experimental hall
- The clean room will allow dedicated string assembly over the life of the project – being installed and ready November 2024



# TRIUMF SRF Facilities

# New Hi-Lumi Area



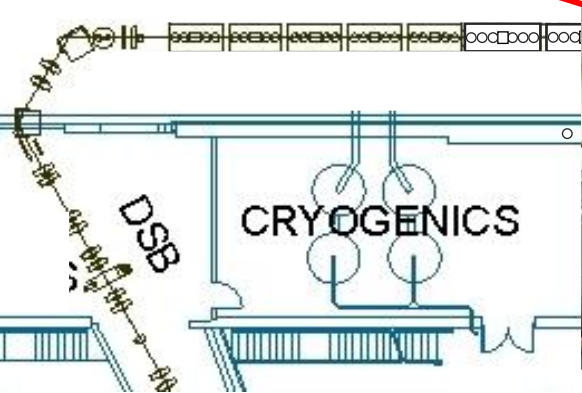
**Dirty assembly**

**Clean assembly**

**Prep room**  
**RF** **HPWR**  
**Cavity/CM testing** **Clean assembly**

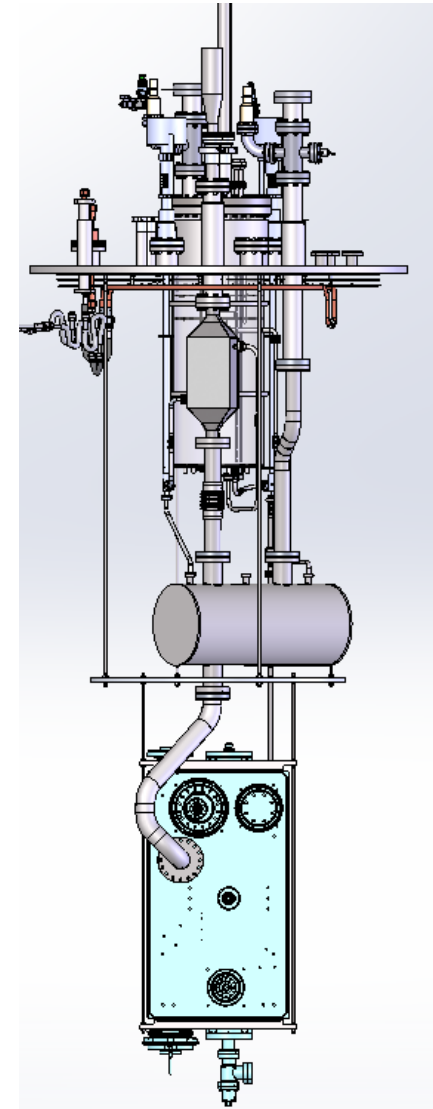
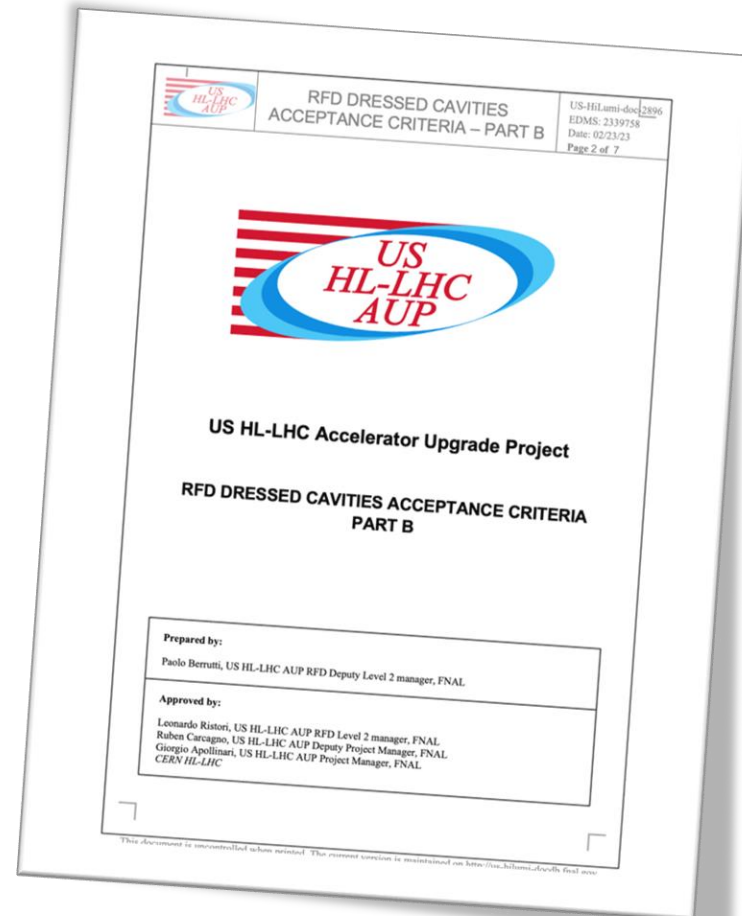


**BCP**



# Preparation for cavity testing

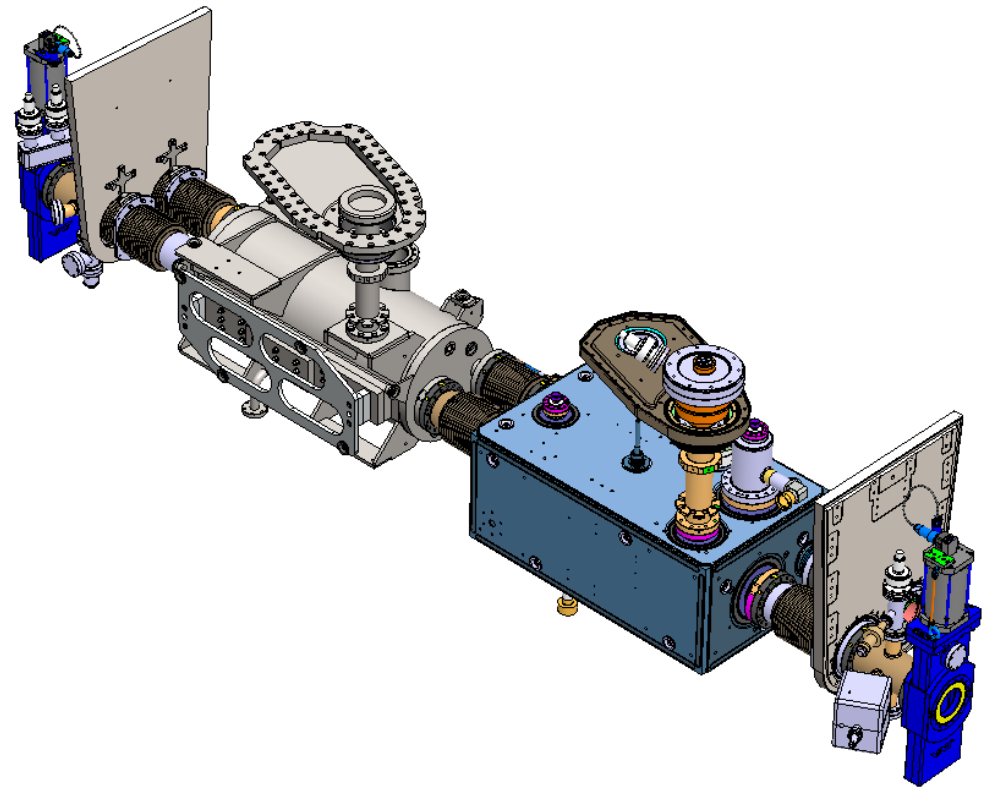
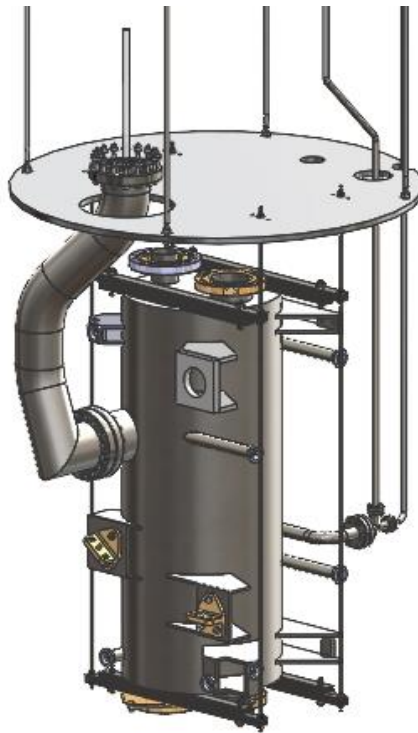
- TRIUMF will requalify the AUP cavities upon delivery from JLab
- TRIUMF has upgraded the cavity test facility
- Prepared and qualified cryo-insert for multi-purpose cryostat to test dressed cavities at 2K in jacketed mode
- Worked with AUP to draft cavity requalification test criteria





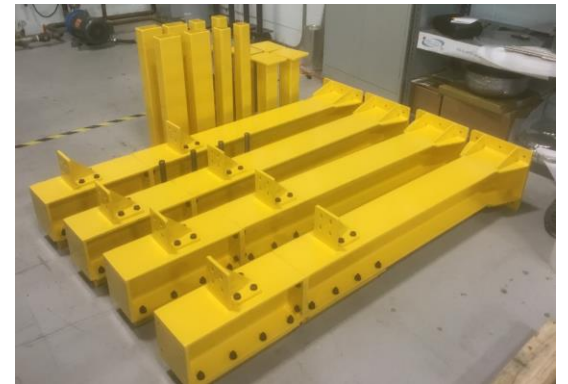
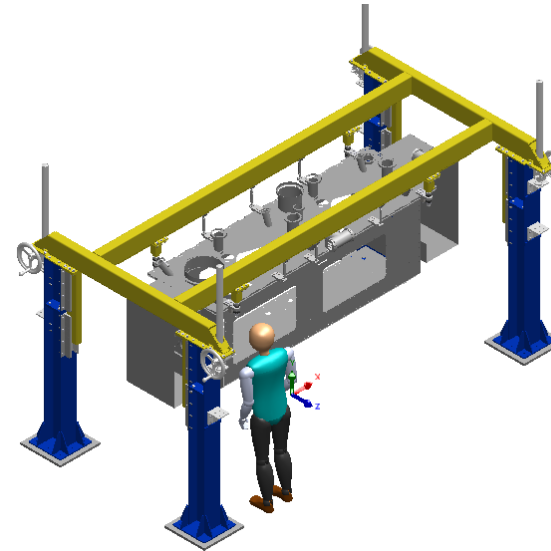
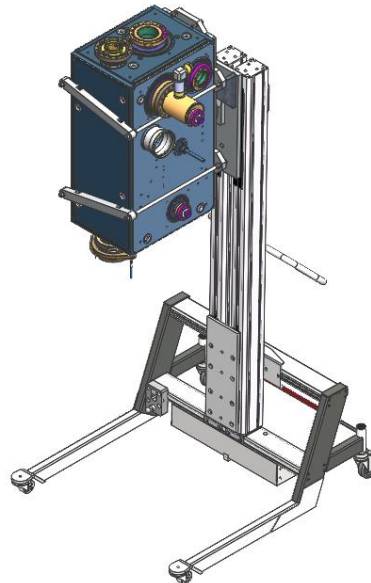
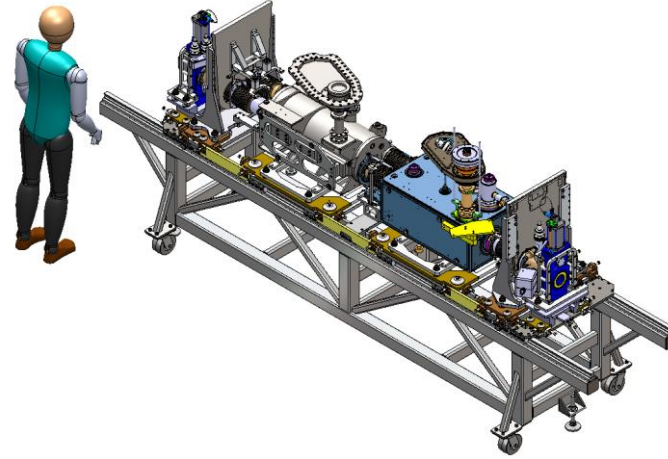
# Dummy cavity for TCM0

- AUP anticipates only one TCM0 cavity in Feb. 2025
- TRIUMF has designed and fabricated a dummy cavity to replicate the RFD cavity
  - Identical LHe volume and mass as the actual cavity
  - Identical beam and helium interfaces as the RFD cavity
  - Identical support interfaces
- Will be used for testing prior to cavity delivery and during assembly of TCM0 cavity string



# Other Infrastructure

- String assembly frame received
  - Based on UK design
  - Ready for assembly
- Top assembly frame
  - Assembled and ready for TCM0
- Cavity manipulation/rinsing tooling
  - Received
- Pumping/Venting stand
  - Ready for commissioning



# Infrastructure upgrade status

		specified	designed	ordered	received
Clean room upgrade	New clean room	✓	✓	✓	Nov 2024
	Rinse facility	✓	✓	Nov 2024	Jan 2024
	Pumping/venting	✓	✓	✓	✓
Cavity testing	4k/2k insert	✓	✓	✓	✓
	Test diagnostics	✓	✓	✓	✓
	Clean venting system	✓	✓	✓	Oct. 2024
	Qualification (dummy cavity)	✓	✓	Nov 2024	Dec 2024
Assembly fixtures	Hermetic string cart	✓	✓	✓	✓
	Dummy cavity	✓	✓	✓	✓
	Cavity handling tooling	✓	✓	✓	✓
	Top down assembly stand	✓	✓	✓	✓
	Cryomodule trolley	✓	✓	✓	✓

## Recent milestones - Cryomodules

<b>Milestone</b>	<b>Application</b>	<b>Achieved</b>
Clean room contract issued	Infrastructure	Sep 2023
OVC material order received	TCM1-5	Feb. 2024
OVC fabrication order launched	TCM1-5	Feb 2024
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Thermal shield fabrication launched	TCM1-5	Sept. 2024
String assembly cart complete	Infrastructure	Sept. 2024

# Cryomodule fabrication milestones

## Outer vacuum chamber (OVC)

- TCM0 and Series contract issued to Axton (Vancouver)
- Material for five OVCs received

## Mu-metal series

- Three articles received with all expected by Dec. 2024

## Thermal shield - series

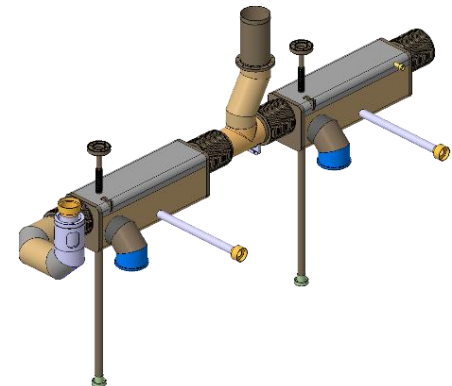
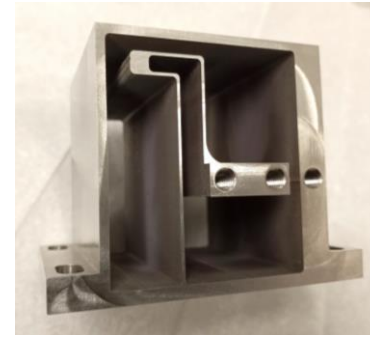
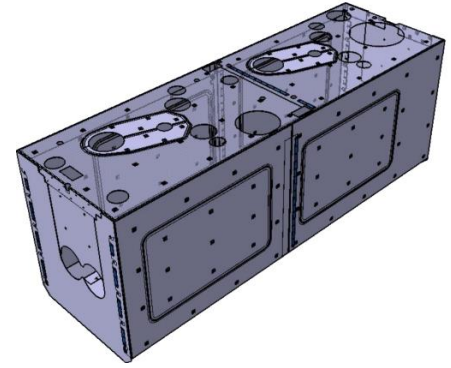
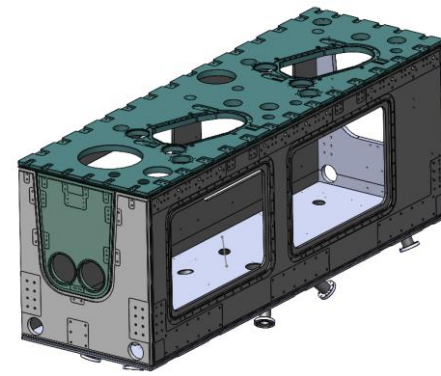
- Material in hand and major fabrication contracts launched

## Tuner - series

- Tuner frame fabrication launched

## Bi-phase lines

- Production well advanced at CERN with first article for TCM1 delivered



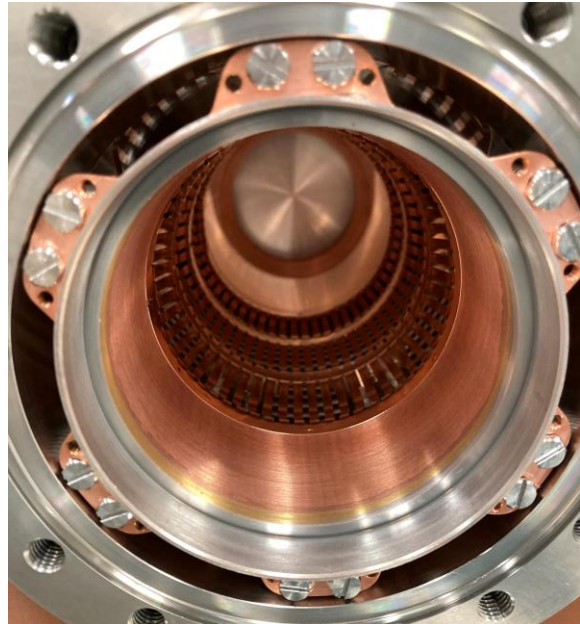
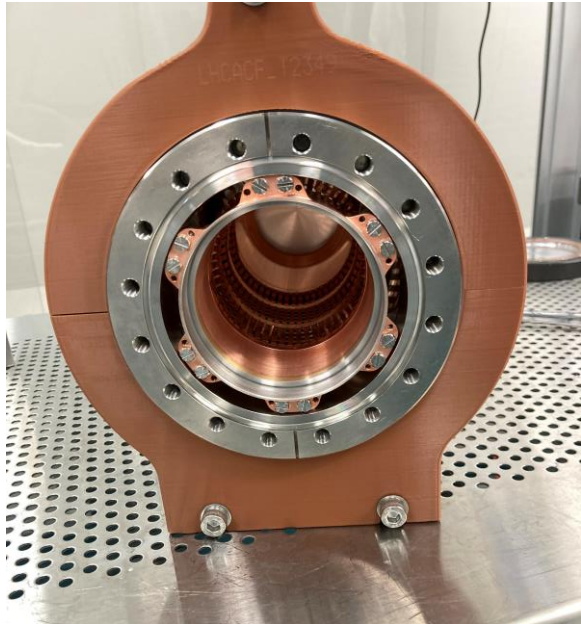
# OVC Status



Document Name	Action	Status 2023	Status 2024
3D Models	N/A	Completed	Completed
2D Drawings	N/A	Completed	Completed
Manufacturing drawings	TRIUMF	In Progress	Completed
Manufacturing and Inspection Plan (MIP)	Axton	In Progress	Completed
Welder Certification	Axton	In Progress	In Progress
Welding Procedure Specifications (WPS)	Axton	In Progress	In Progress
Welding Procedure Qualifications Records (WPQR)	Axton	In Progress	In Progress
Raw material certificates	TRIUMF	In Progress	Completed
Filler material certificates	CERN	In Progress	Completed
Material samples	TRIUMF	In Progress	In Progress
Scheduling (incl. preliminary dates)	Axton	In Progress	Completed
Traceability procedure	Axton	In Progress	Completed
Cleaning procedure	TRIUMF	In Progress	Completed
Leak test procedure	TRIUMF	In Progress	Completed

## First PIMs received from CERN

- Components for first string assembly
- Tested in clean room for particulate



# Summary

- 2024 strategy addresses finite time window for available funds
  - Requires timely delivery from vendors (and CERN) of agreed deliverables in order to make payments
- Preparing TCM0 and series production CMs
  - OVC production launched – series
  - OVC material received - series
  - Mu-metal – 3 articles received
  - First out of scope fabricated parts received from CERN
- Cavity testing infrastructure
  - 4k/2k assembly tested and meets all specs
  - Pumping station installed
  - Ready for 2k testing
- New clean room being installed for Nov. 2024 commissioning
- Major assembly infrastructure in hand





## Backup slides

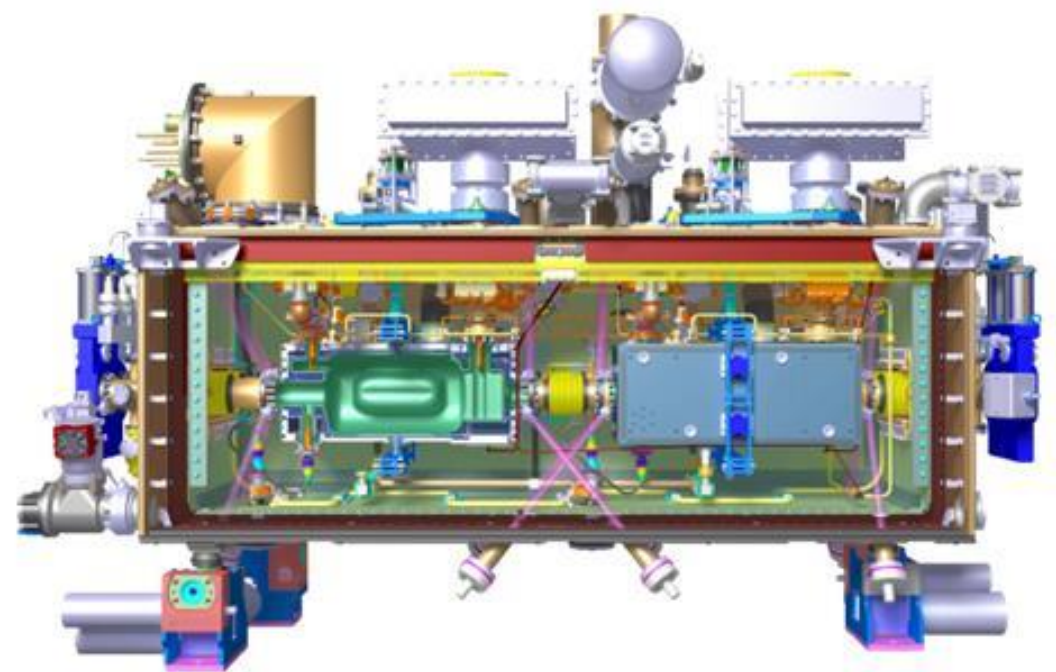
# Cavity Re-qualification at TRIUMF

- CERN acceptance of AUP cavities will happen at TRIUMF
- Acceptance criteria are established in a document from AUP following CERNs engineering specification
- TRIUMF will receive qualified cavities under vacuum and with test coupler and vacuum diagnostic on board
- The acceptance document itemizes a series of warm and cold measurements to confirm that the cavity has not been degraded during transport and is acceptable to be installed in the CM.



# Cryomodule Qualification/Commissioning at TRIUMF

- To verify as many performance requirements as possible in cold test
- Requirements can be found in CM engineering specification (EDMS 2043014)
  - Vacuum cycles
  - Warm RF checks
  - Cooldown to 77K
  - Cooldown to 4K
    - Heat loads at 4K
    - RF tests at 4K
    - alignment check
  - **No 2K test**



A test plan is being drafted.

A CM test is expected to take 4 weeks with 1 week of preparation, 2 weeks of testing and 1 week of warm-up and removal.

The amplifier will be supplied by CERN