ESS High-Beta Cavities

Procurement & Quality Control

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ESS High Beta Cavities

- Introduction
- STFC & IKC scope for ESS HβC
- Schedule & concurrent engineering challenges
- Procurement
  - Nb + cavity fabrication strategy
  - Cavity fabrication responsibilities
- Quality Assurance schemes
  - Overview
  - Acceptance levels
  - Detailed scheme
- Spare slides: HβC (H) Vertical Test Facility preparations

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STFC Scope for ESS Hβ Cavity

STFC UK In-Kind Contribution:

- Bespoke 704.42 MHz 'horizontal' Vertical Test Facility
- Niobium procurement
- Manage Eddy Current Scanning (DESY)
- Validation of industry processes using 'pre-series' cavities
- Cavity fabrication of 84 (+4) high beta cavities in industry
- 2K RF qualification of cavities to 20.9MV/m, $Q_0 \geq 5 \times 10^9$
- Transport to Saclay

Outside STFC Scope

- Cavity design
  - STFC strategy mix: mainly "build-to-print"
  - only essential adaptations for industry (prototypes fab @ CEA)
- Prototype cavities (CEA Saclay)

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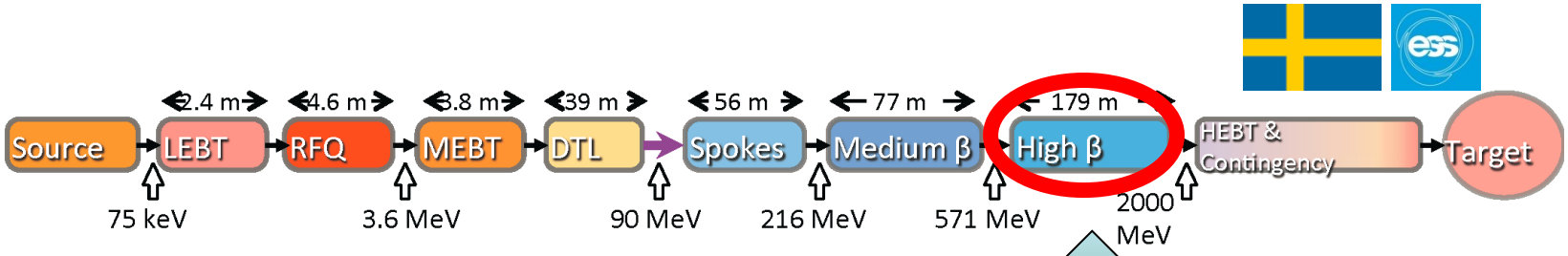
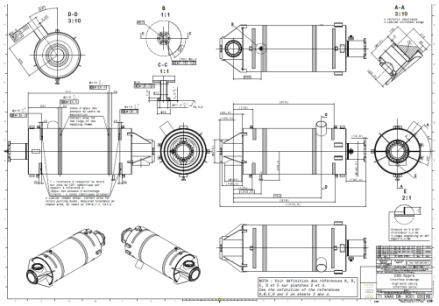
ESS Cryomodule IKC Collaborators

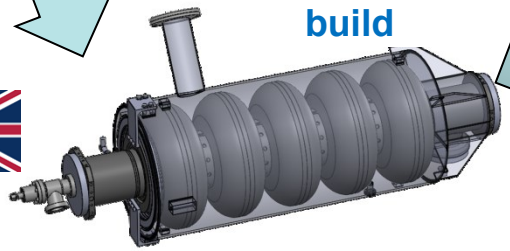


Cavity Design & Specification



Production + assembly x 21 Hβ Cryomodules

Procure & build



x 84(+4) Hβ SRF cavities

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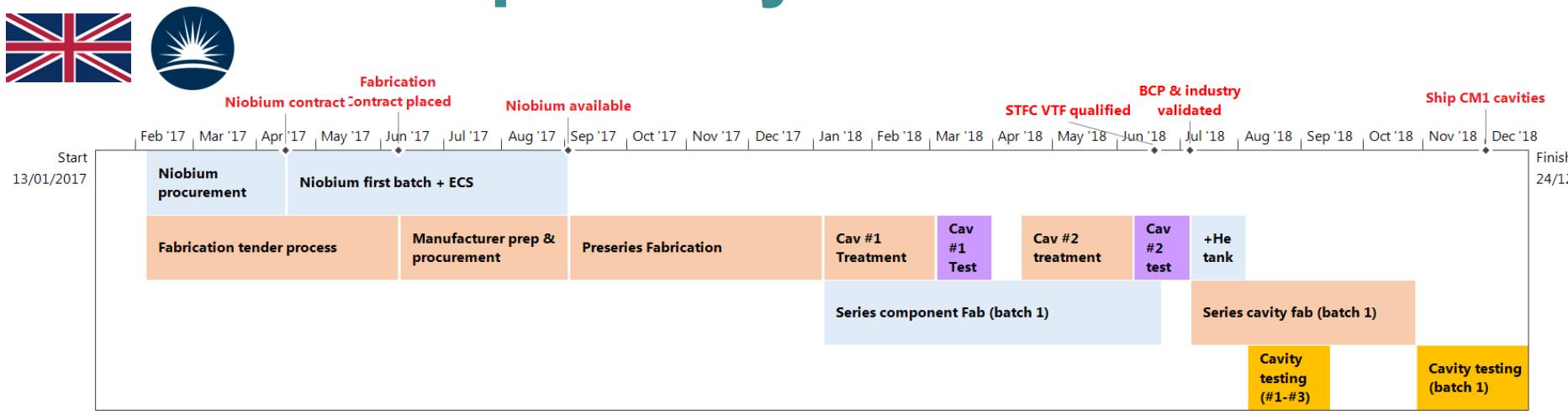
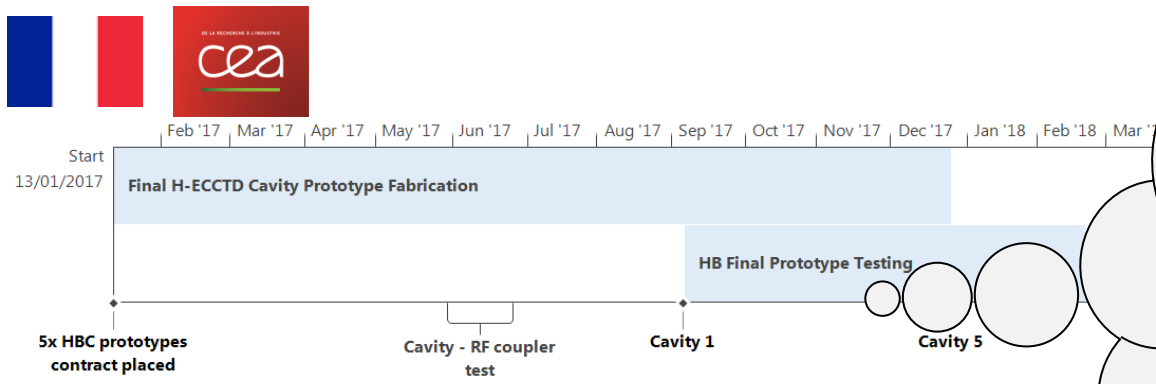
Hβ Cavity Schedule





Concurrent engineering

- May accelerate schedule
- Risk of change *vs* opportunity for early test data
- Requires robust systems for:
  - Change control system
  - Configuration mgmt
  - Communications
  - Risk mgmt

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Procurement: Cavity & Nb

Single vendor for all Nb, Single vendor for all cavities

- Don't have team bandwidth to validate & manage 2+ vendors
- Vendors' capacity sufficient (faster than STFC testing!)

Open tenders

- Schedule & budget did not allow pre-qualification
- Requires very careful procurement selection questions & quality measures

Cavity design specification:

- Mechanical drawings
- RF & 'performance' requirements
- Quality control measurements & checks
- Cavity treatment specifications (BCP, heat + vacuum, etc)

Specification development:

- Original aim to launch tenders with precisely defined specification
- Ongoing development of cavities & cryomodules (CEA Saclay)
- More flexible approach: high level specification for tender
- Final specification agreed in formal kick-off mtg

Procurement: Cavity & Nb

Open questions:

- Cavity fabrication: Precise, detailed specification vs ‘flexible’ specification & use of industrial know-how?
  - Experienced suppliers know how to make cavities

- Concurrent engineering:
  - ‘Indicative’ vs ‘final’ specification in OJEU tender process?
  - Which specification elements most drive cavity cost / schedule?
  - Incorporating learning from prototypes (CEA) into series (STFC)?

- Responsibility:
  - What constitutes “cavity design”?
  - Collaborative vs build-to-print?

Preseries Fabrication Procurement

Industry:

- Manufacturing drawings, tooling, final process specifications
- Produce pre-series undressed cavities
- Propose trimming, cavity component selection
- Optimise / validate treatment processes
- All treatments (BCP, tuning, annealing, HPR etc)
- Collect all QA data & reports
  - Dimensional, RF frequency /spectra, vacuum etc
  - Treatment process parameters
  - Align to acceptance levels required
- Helium tank integration after 2K undressed test

Cavity undressed testing @ 3rd party (TBD)

- 2K test of undressed cavities

STFC:

- Specify “high level” QA data required & approve manufacturer’s QA report templates
- Supervision of all steps
- Approve manufacturing plans & detailed manufacturing drawings
- Approve treatment processes
- Approve component trimming, composition etc
- Review & approve Acceptance Level data
- Cold RF test of dressed cavities

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Series Fabrication Procurement

Industry:

- Optimise QA data & reports for series (joint with STFC)
- Mechanical fabrication of cell & cavity components
  - (Starts in parallel with treatments of pre-series cavities)
- Propose trimming, cavity component selection
- All treatments (BCP, tuning, annealing, HPR etc)
- Collect all quality data & reports
  - Dimensional, RF frequency /spectra, vacuum etc
  - Treatment process parameters
  - Align to acceptance levels required
- Helium tank integration

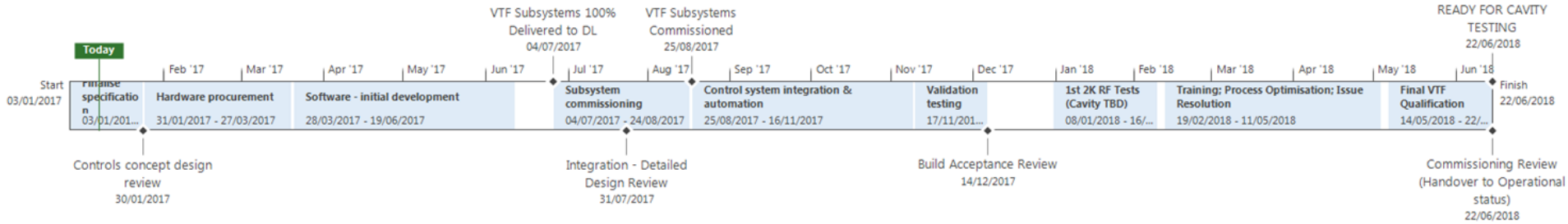
STFC:

- Optimise QA data & reports for series (joint with industry)
- Supervision of all steps
- Approve component trimming, composition etc
- Review & approve Acceptance Level data
- 2K RF test of dressed cavities
- Shipping of qualified cavities
- 1x HPR of non-conforming cavities where required after 2K RF test

Quality Assurance

- (H) Vertical Test Facility
  - Design process w/ formal checkpoints
  - Commissioning process fully documented
  - Qualification against known cavity performance
- Niobium supply
  - Industry provides Nb ingot & sheet samples
  - DESY to perform Eddy Current Scanning (directly contracted to ESS)
- Cavity fabrication
  - Industry provides QA measurements
  - STFC approve
  - STFC / ESS (+CEA Saclay) jointly review Non-Conformances
- Cold testing
  - Incoming, outgoing inspections & tests
  - 2K cavity RF testing by STFC
  - If required, 1x HPR per cavity + retest at STFC
  - Defined, controlled & repeatable processes for all steps

QA: Facility Validation



- **Facility commissioning & validation plan in development**
  - Cleanroom & HPR process validation
  - Commissioning each subsystem independently
  - Integration of hardware & controls
  - Process development & staff training
  - RF measurement repeatability & accuracy: cross-reference to other labs?
  - Transport, shipping & cavity handling tools & processes

- **Collaborative effort (STFC, ESS, CEA, INFN) to define:**
  - Document storage systems
  - Reports & data parameters / criteria
  - Cavity material & fabrication data requirements
  - SRF test data

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QA: Cavity Fabrication

Acceptance level	Assembly stage	Data types	Data from	Approver
0 (tbc)	Half-cells End groups	Mechanical, RF, visual	Mfg	Mfg Preseries: STFC?
1	Assembled cavity Surface treatment	Mechanical, RF, vacuum, visual	Mfg	STFC
2	Tank integration, final treatment	Mechanical, RF, vacuum, treatments, tank	Mfg	STFC
3	Final assembly	Treatment, RF, vacuum, transfer measurements, accessory BoM, visual, packing, Factory Outgoing	Mfg	STFC
4	After 2K RF test	STFC Receiving, RF performance, STFC outgoing, HPR (if performed)	STFC	ESS (CEA?)
5	Ready for CM string assembly	CEA incoming (visual inspection, G-shock log reading, vacuum, RF antennae?)	CEA	ESS

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QA: Cavity Fabrication

Acceptance level	Assembly stage	Data types	Data from	Approver
0 (tbc)	Half-cells End groups	Mechanical, RF, visual	Mfg	Mfg Preseries: EC?
1	Assembl Surface			
2	Tan fi			
3	Fi			
4	Af			ɔɔ (CEA?)
5	Ready for C string assembly		CE	ESS

- **Formal review points**
- **Aligned to INFN proposal for ESS Mβ cavities**
- **Based on proven XFEL schemes**
- **Consistent across ESS collaborators**

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QA: Cavity Fabrication

Niobium Acceptance

Acceptance level 1

A.L. 2

Acceptance Level 3

Nb (cell), Nb/Ti (flange) and Ti (He vessel) Material	Certification	Inspection	Test/Measurement	Procedure	Analysis	Data Type	Frequency
Cavity Cell Nb Material							
Vendor certification	Y						
RRR			Y			Data Array (from RRR instrument)	Single Measurement
Thickness			Y			Data Array (from CMM)	Single Measurement
Eddy current qualification (possible)					Y		
Water test verification			Y		Y		
Magnetic field characterisation	Y		Y	Y		Data Array (from Hall Probe)	Single Measurement
Qualification and test procedures				Y		Procedure Document	
Flange Nb/Ti Material							
Vendor certification	Y						
Dimensional comformance			Y	Y		Data Array (from Hall Probe)	Single Measurement
Magnetic field characterisation	Y		Y	Y		Data Array (from Hall Probe)	Single Measurement
Ti helium vessel							
Vendor certification	Y						
Dimensional comformance			Y	Y		Data Array (from Hall Probe)	Single Measurement
Magnetic field characterisation	Y		Y	Y		Data Array (from Hall Probe)	Single Measurement
Cavity Fabrication							
Receipt of Nb and Nb/Ti material from vendor		Y				Inspection Report	
Cavity fabrication process				Y		Procedure Document	
Cavity cell forming validation (CMM)			Y	Y	Y	Data Array (from CMM)	Single Measurement
Cavity cell forming validation (RF)			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Cavity cell wall uniformity			Y	Y	Y	Data Array (from CMM)	Single Measurement
Cell preparation prior to EBW (BCP)				Y		Procedure Document	
EBW parameters	Y			Y		Procedure Document	
Dumbell frequency verification			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Cavity alignment			Y	Y	Y	Data Array (from CMM)	Single Measurement
Cavity frequency tuning			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Field flatness			Y	Y	Y	Data Array (from Bead-pull system)	Single Measurement
HOM characterisation			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
BCP procedure	Y			Y	Y	Procedure Document	
HPR procedure	Y			Y	Y	Procedure Document	
Probe coupling measurement				Y	Y	Data Array (from Network Analyser)	Single Measurement
Vacuum leak check	Y			Y	Y	Procedure Document	
RGA scan	Y			Y	Y	Data Array (from RGA)	Single Measurement
Cavity QL measurement	Y			Y	Y	Data Array (from Network Analyser)	Single Measurement
Helium vessel Fabrication and attachment							
Receipt of Ti material from vendor		Y				Inspection Report	
Helium vessel fabrication process				Y		Procedure Document	
Attachment of helium vessel to cavity				Y		Procedure Document	
HOM characterisation			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Probe coupling measurement			Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Vacuum leak check	Y			Y	Y	Procedure Document	
RGA scan	Y			Y	Y	Data Array (from RGA)	Single Measurement
Cavity QL measurement	Y		Y	Y	Y	Data Array (from Network Analyser)	Single Measurement
Cavity VTF Assembly							
Receipt of Cavities from industry		Y				Inspection Report	
Dimensional and RF measurements			Y	Y	Y	Data Array (from NA and CMM)	Single Measurement
Assembly onto insert in Cleanroom	Y		Y	Y	Y	Procedure Document	
Diagnostics assembly (thermocouples)				Y		Procedure Document	
Assembly in VTF				Y		Procedure Document	
Interface connections (RF, vacuum, Cryo, diagnostics)			Y	Y		Procedure Document	
Application of LHe	Y			Y	Y	Procedure Document	
Cavity Performance Testing							
RF, temp and vacuum measurements during cooldown			Y	Y	Y	Data Array (from control system)	60 secs (?)
Cryogenic pressure stability			Y	Y	Y	Data Reading	Single Measurement
Cryogenic temperature			Y		Y	Data Reading	Single Measurement
VTF LHe level			Y		Y	Data Reading	Single Measurement
RF power			Y		Y	Data Reading (from control system)	Single Measurement
Cavity temperature (cavity x2, end group x2, helium jacket x2, flanges x2)			Y		Y	Data Array (from control system)	Single Measurement
Cavity vacuum			Y		Y	Data Reading (from control system)	Single Measurement
Cavity frequency			Y		Y	Data Reading	Single Measurement
Qo			Y	Y	Y	Data Reading	Single Measurement
Gradient			Y		Y	Data Reading	Single Measurement
Qo			Y		Y	Data Reading	Single Measurement
Microphonics			Y	Y	Y	Data Array	Single Measurement
Cavity Test Configuration							
To be included in this section:							
1. Full details of all test and measurement equipment used (Make, model, serial number, configuration settings etc)							
2. Relevant calibration information							
3. Serial number and location on VTF insert							
Cavity Test Diary							
A full chronological record of all significant events in the testing process including:							
1. Date/Time							
2. Details of test or procedure							
3. Person responsible							
4. Comments							

- Detailed STFC cavity QA scheme in development
- Aligning with known systems
  - XFEL, LASA, industrial experience
- Incorporate prototype learning
- Incorporate any requirements specific to ESS Cryomodule design
- Will include all required control measurements
  - RF frequency, FF, HOM spectra
  - Mechanical dims, CMM etc
  - Visual inspections, ultrasound
  - Treatment parameters
  - Mass measurements

Thanks & acknowledgement to DESY, INFN, CEA for guidance & advice on series QA

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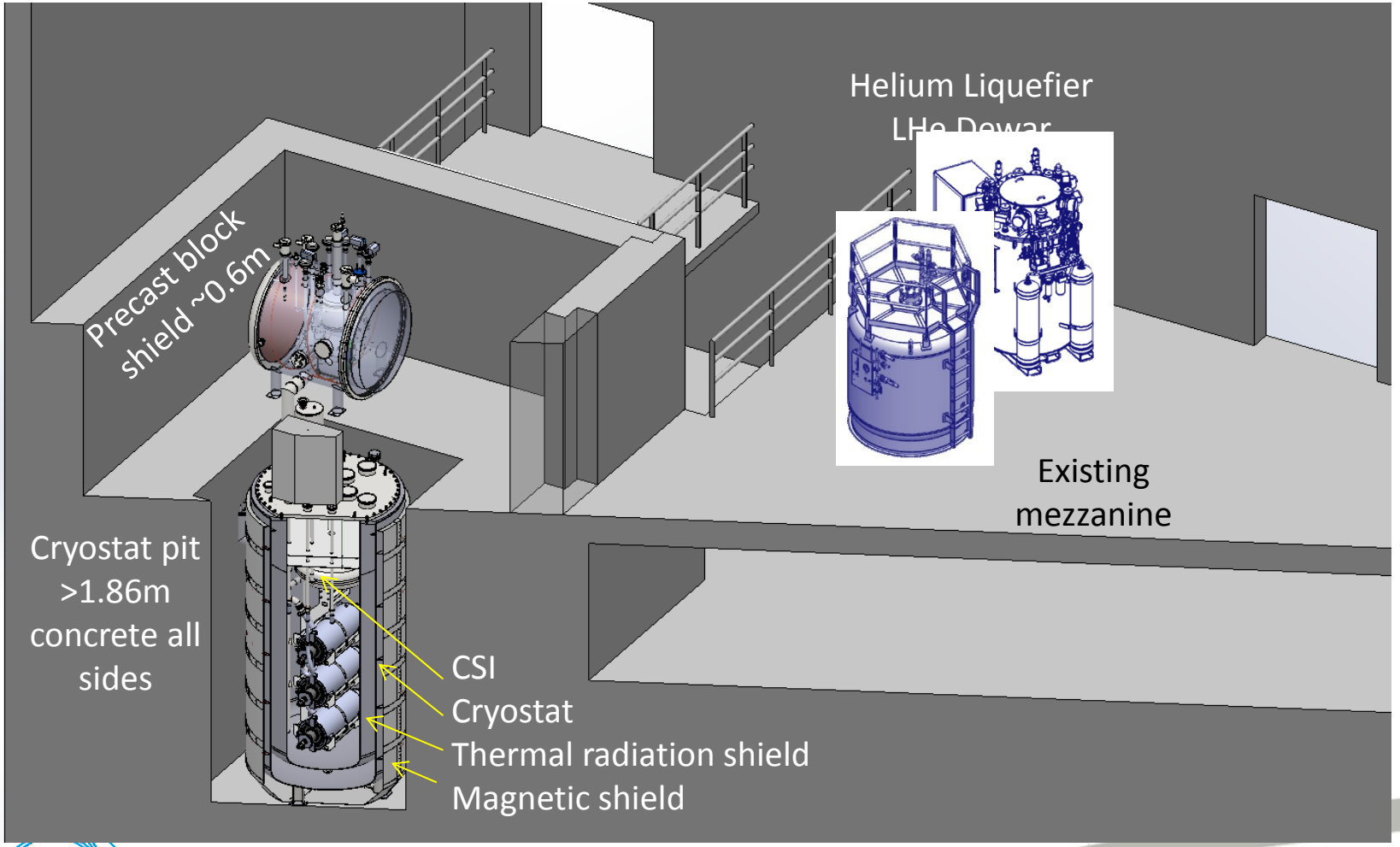
Additional slides

- VTF & shielding design cut-away view
- Cryostat & inserts
- Modular cleanroom / VTF assembly area
- Cryoplant subsystem
- Modular Cleanroom
- Main cleanroom & HPR
- RF system
- VTF overview
- Cavity interfaces to STFC cryostat

VTF & Shielding Overview



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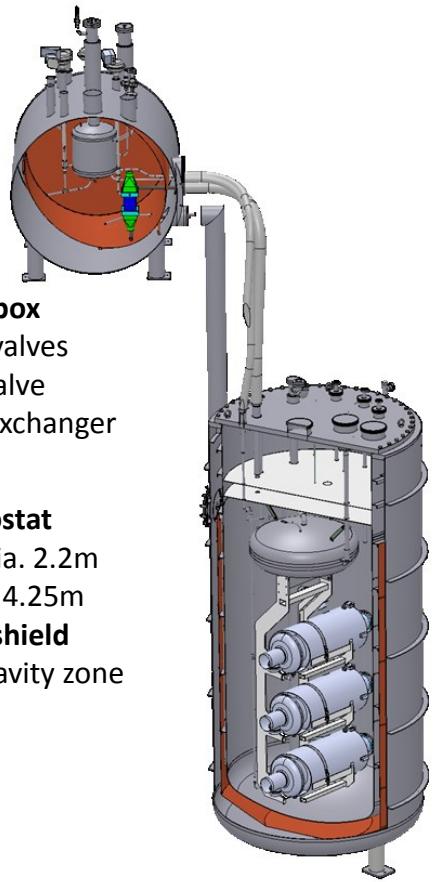
Cryostat & Inserts

- ‘Horizontal’ VTF
- Previously presented by Shrikant Pattalwar, TTC 2015



2K box
Cryo valves
JT valve
2K Heat exchanger

Cryostat
Outer dia. 2.2m
Height 4.25m
Mag shield
<1uT in cavity zone

Inner vacuum vessel being manufactured at Criotec (26/01/2017)

Radiation shield being manufactured at Criotec (26/01/2017)

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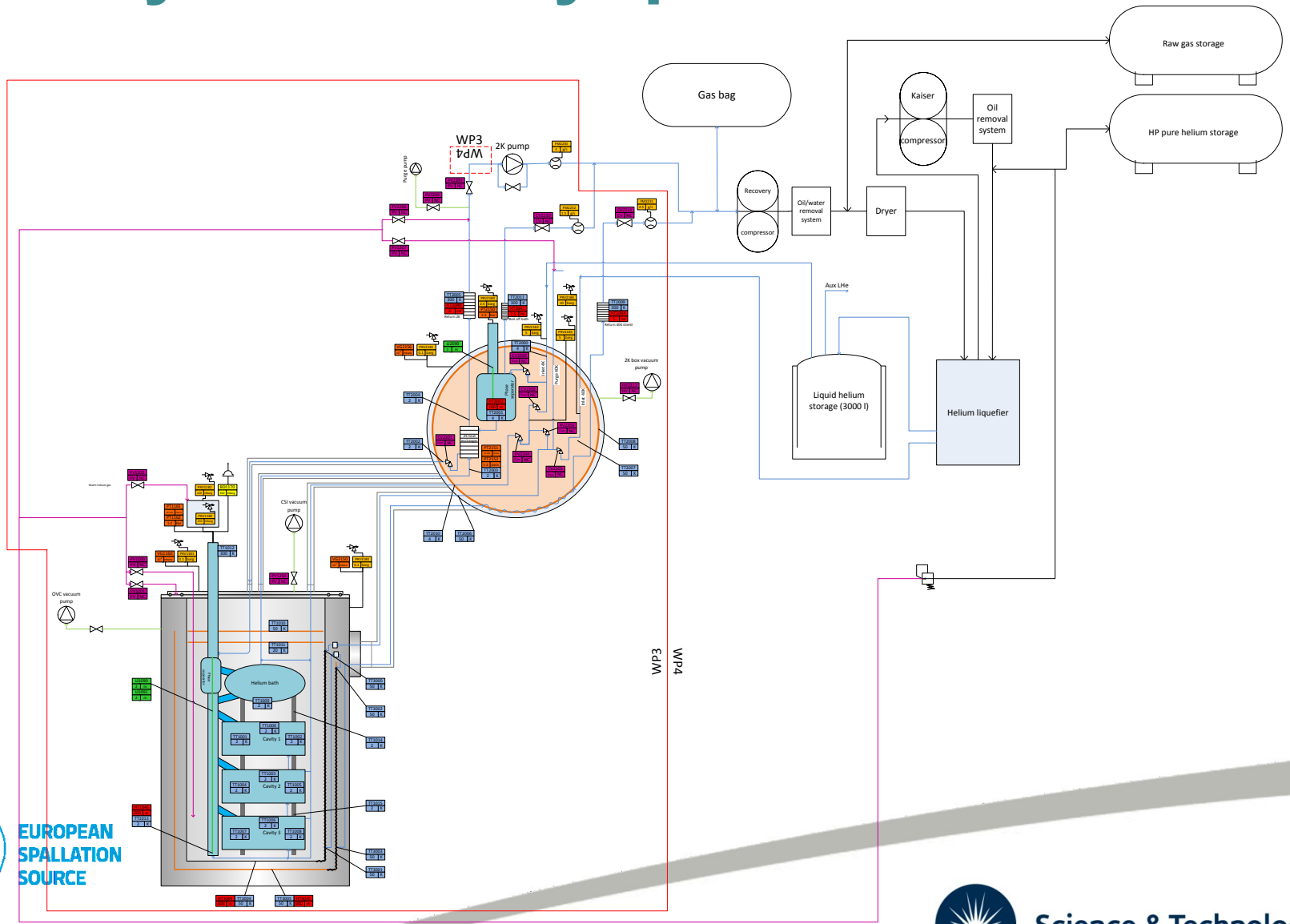
Cryostat & Cryoplant Scheme



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STFC Cryo plant – first plant arriving

15 Jan 2017: Delivery 1

- Compressor
- Oil removal system

Right:
View overlooking future cryostat & radiation shielding bunker
Cryoplant components should be moved to compressor building this week

Remaining components due late Feb 2017

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Modular cleanroom concept

← To cryostat & bunker

Modular cleanroom for UHV cavity connections

Two options under test / evaluation

1. Glovebox
   - reduced cleandown
2. Walk-in area
   - simpler ergonomics

Dummy cavity manufactured from SS316

Ultrasonic clean & degrease

Particle counting just downstream of UHV valve area

Good initial results in large walk-in volume

Also now developing ‘glove box’ solution to test ergonomics.

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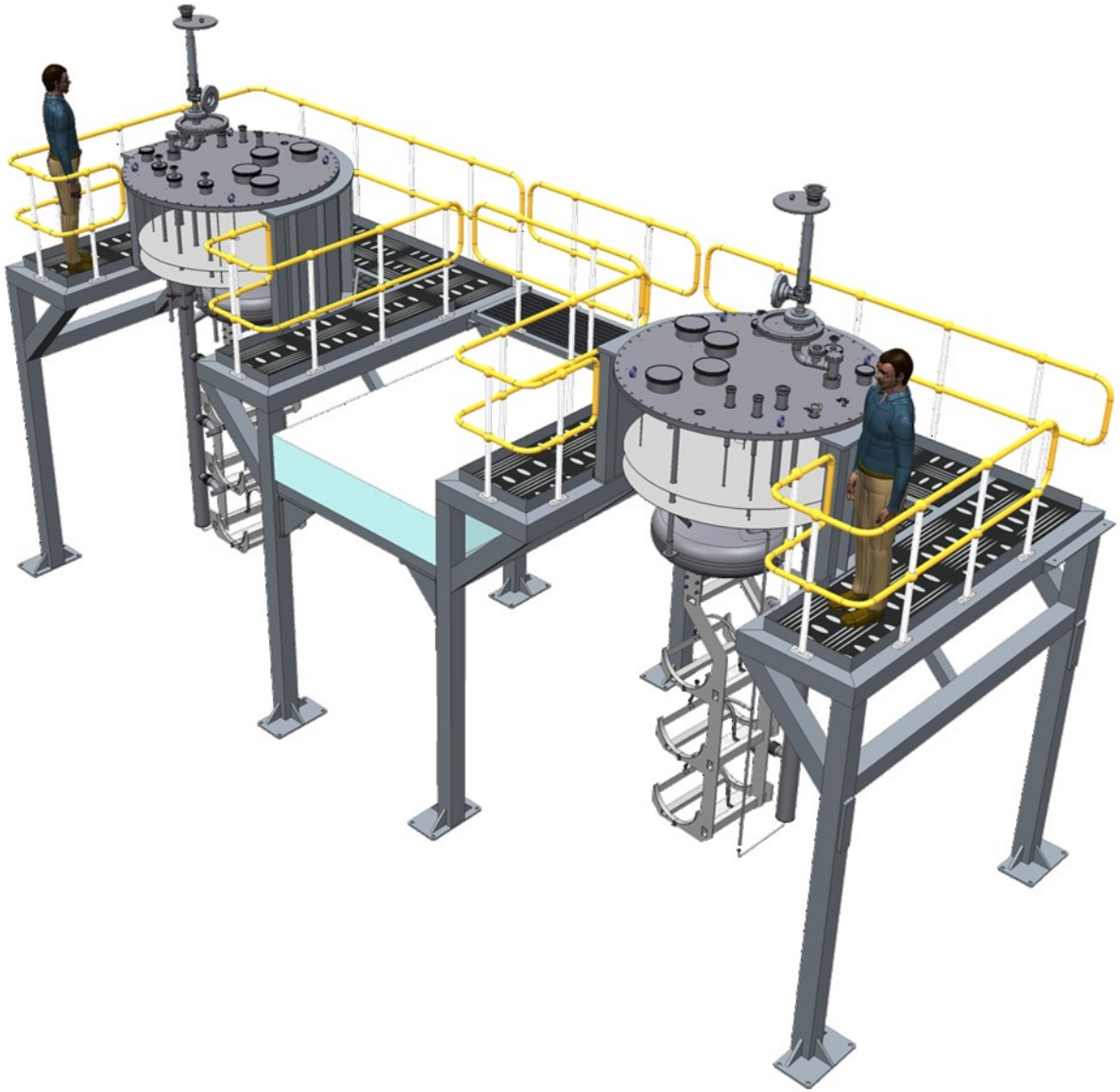
Modular cleanroom / CSI stand



Concept design for VTF assembly area

- Support 2x cryostat inserts
- Access to UHV & cryo instrumentation on top flanges
- Access to cavity connections on lower section
- Flexible / modular options for integration particulate control systems
  - Fan filter units
  - Laminar flow units
  - Screens
  - Glovebox

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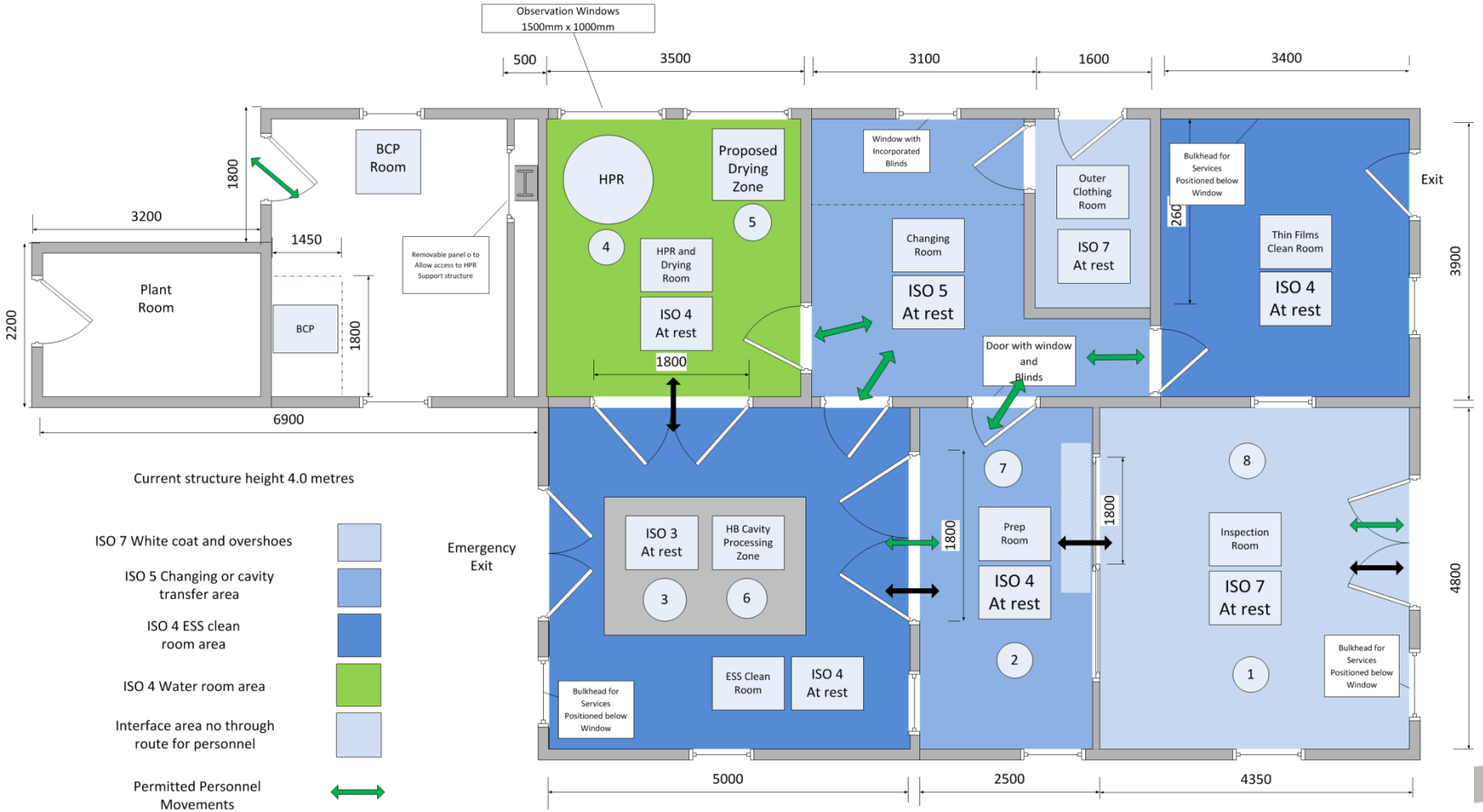
Cleanroom & HPR



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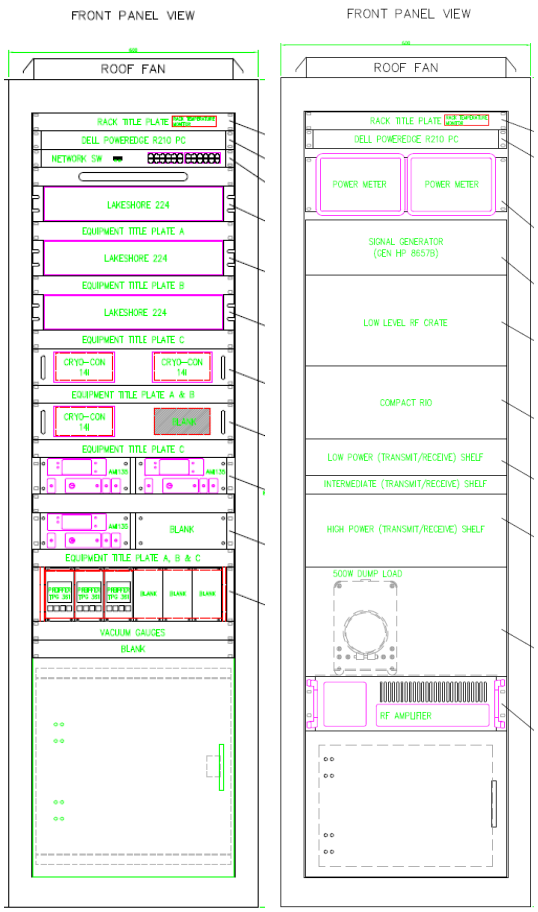
RF System



High level design complete

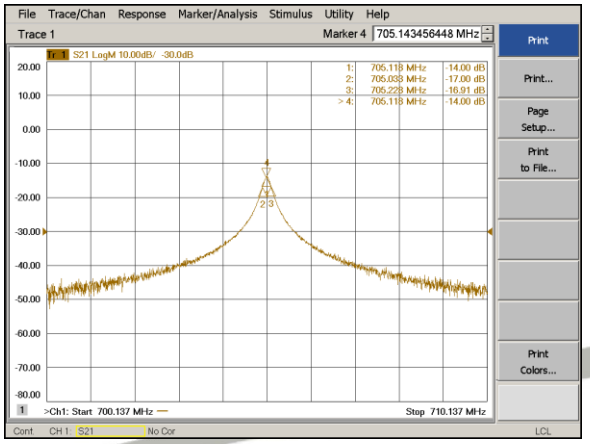
LLRF detailed design ongoing

- based on JLab / T Powers LLRF
- Adapted by STFC (K Dumbell, P Smith, F Palade)

Rack design near-complete

Validation with coaxial resonators ongoing

- Cu resonators for basic system functionality
- LLRF validation tests planned using 704.42 MHz Nb SRF coax resonator



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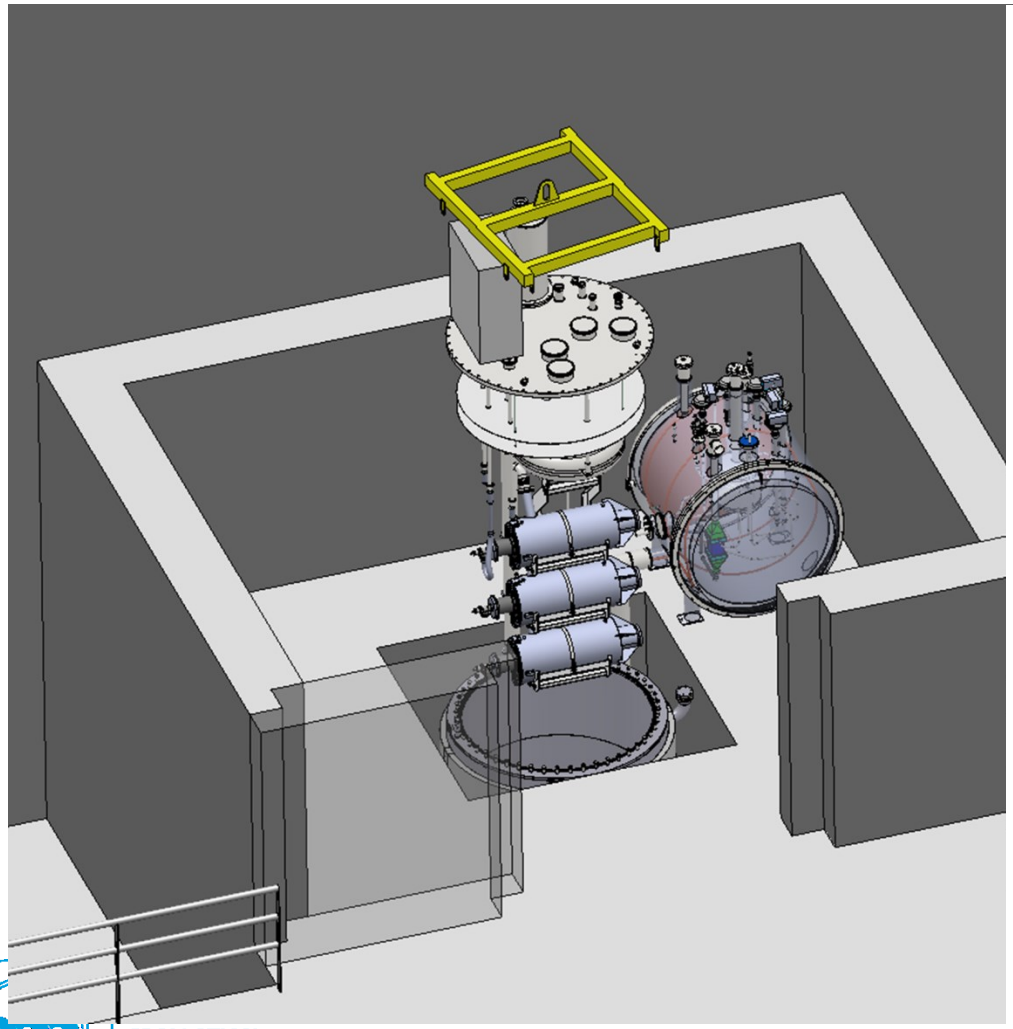
ESS: STFC (H)VTF



- Bespoke vertical test cryostat for ESS HB cavities
- 3 cavities in cryostat
  - Horizontal test configuration
  - **1500L LHe per test**
  - **<4g/s He(g) HVTF**
  - Conventional config:
    - 7500L He(l)
    - 20g/s He(g)
- 2 week test cycle
  - 1 week potential

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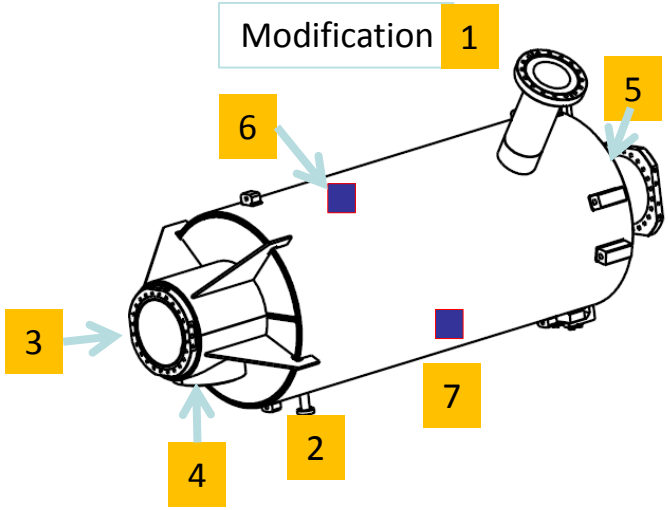
STFC (H)VTF Cavity Interfaces



1. Helium diphase outlet	CF/ISO flange welded to extended pipe
2. Helium inlet port	CF to flexible pipe
3. Beam Pipe Vacuum	Coupler Port (ISO flange + DN40 angle valve *(not shown)*)
4. RF input coupler	Antenna mounted on flange on main input port
5. RF pick up	Pick up point 5 (pickup will remain with cavity in CM)
6. Mounts for T-sensors	Custom instrumentation belt in design, 3 temp sensors
7. Film Heater	50 W

Items 3,4 and 5 factory mounted on the cavity
Cavity transported in Vacuum

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