This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

SRF Cavity Test Capabilities at Daresbury Laboratory

AMICI ETIAM Workshop on Vertical Cavity Testing
14th September 2022

Sean Hitchen

RF Electronic Engineer & VTF Operator

RF and Cryogenic Group - Accelerator Science and Technology Centre – STFC Daresbury Laboratory

sean.hitchen@stfc.ac.uk

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Agenda

1. Introduction
2. VTF System Overview
3. Validation and Cross Comparison
4. Current Challenges + Open Discussion

SuRF Lab Team

RF: P. A. Smith, S. Hitchen, C. Jenkins, M. Jones

Cryogenic: A. Blackett-May, S. Pattalwar, A. Akintola

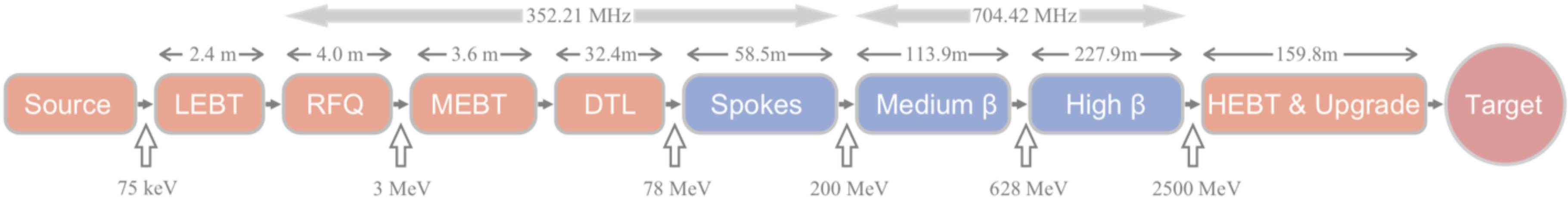
Mechanical: D. Mason, J. Mutch, G. Miller

Vacuum: S. Wilde, K. Middleman, O. Poynton

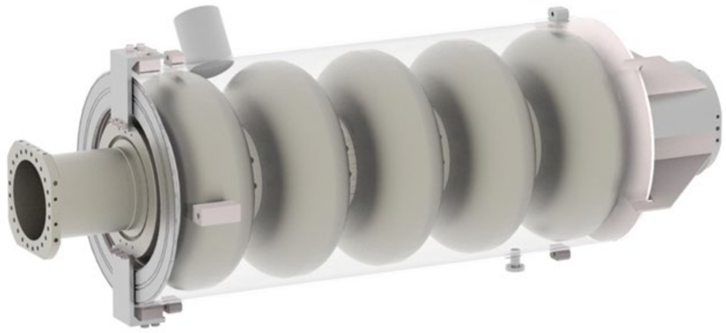
Technical: P. Hornickel, M. Lowe, A. Oates, J. Wilson

ESS and PIP-II Projects: M. Pendleton, M. Ellis, J. Lewis, A. Wheelhouse, P. McIntosh, G. Jones

ESS high-β cavities



- As part of the UK's IKC to the ESS, STFC Daresbury is responsible for the manufacture and qualification of 88 high-beta SRF cavities.
- To date over 36 cavities have be delivery to CEA for cryomodule integration.



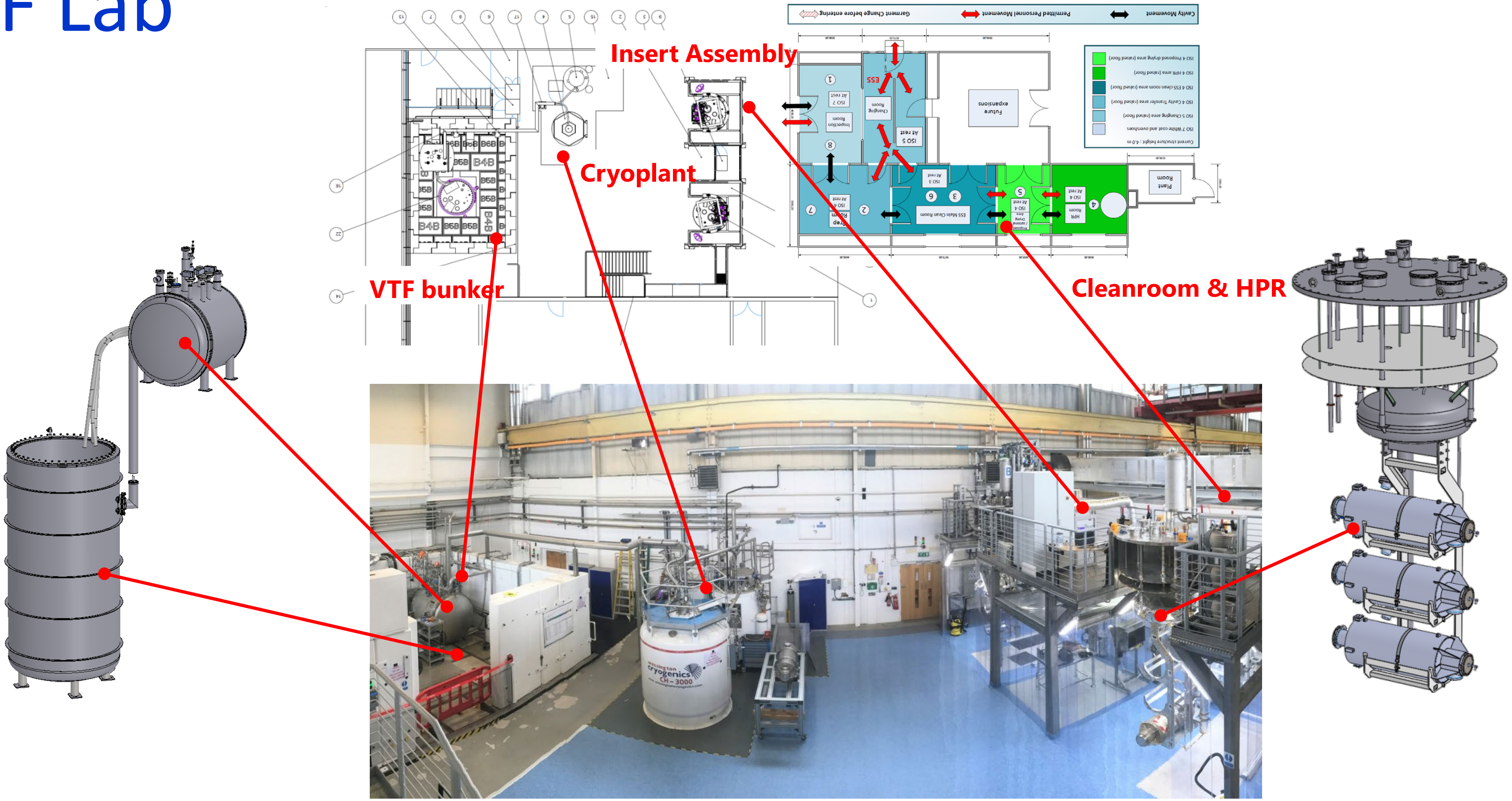
PIP-II Project

- Current VTF Infrastructure has been designed for ESS project. We are currently expanding our capabilities for testing and qualification of cavities for the PIP-II project.
- STFC is also responsible for Cryomodule integration

Cavity Parameters

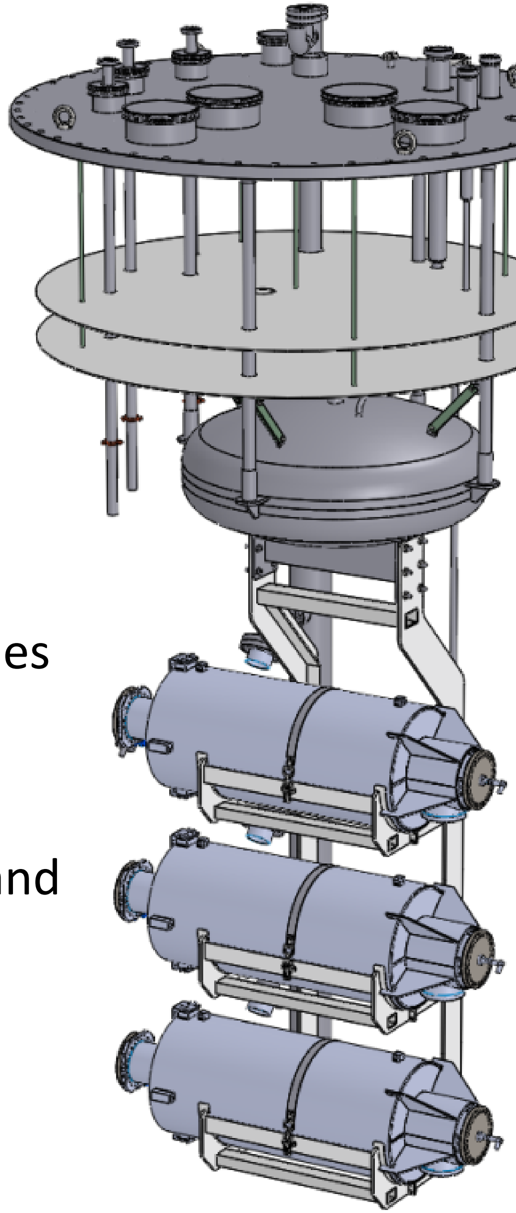
	ESS (Current)	PIP-II (Future)
Frequency	704MHz	650MHz
No. of Cavities	84 (+4)	18 (+3)
No. of Cryomodules	21	3
Accelerating Gradient	19.9MV/m	19MV/m (+20%)
Q0 at Nominal Gradient	5e9	3.3e10 (TBC)

SuRF Lab



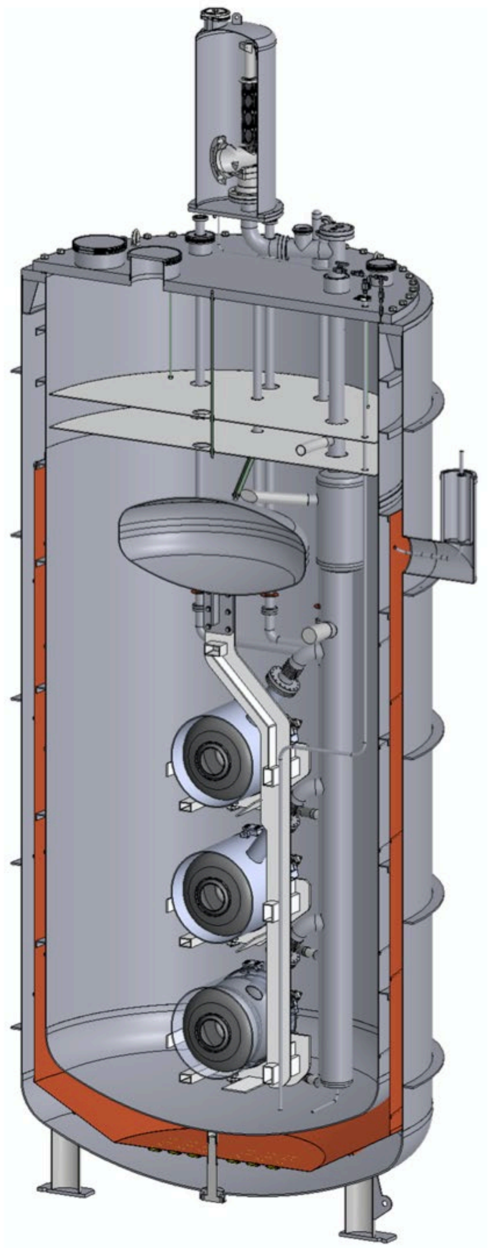
Cavity Support Insert (CSI) Design

- Individual LHe jackets
- 3 Cavities Tested per Cooldown
- “Horizontal” VTF developed at Daresbury allowing test of 3 high-beta cavities per run.
- ~70% Less Helium than conventional facilities.
- Pair of identical CSIs with common cryostat to allow simultaneous testing and preparation of the next set of cavities

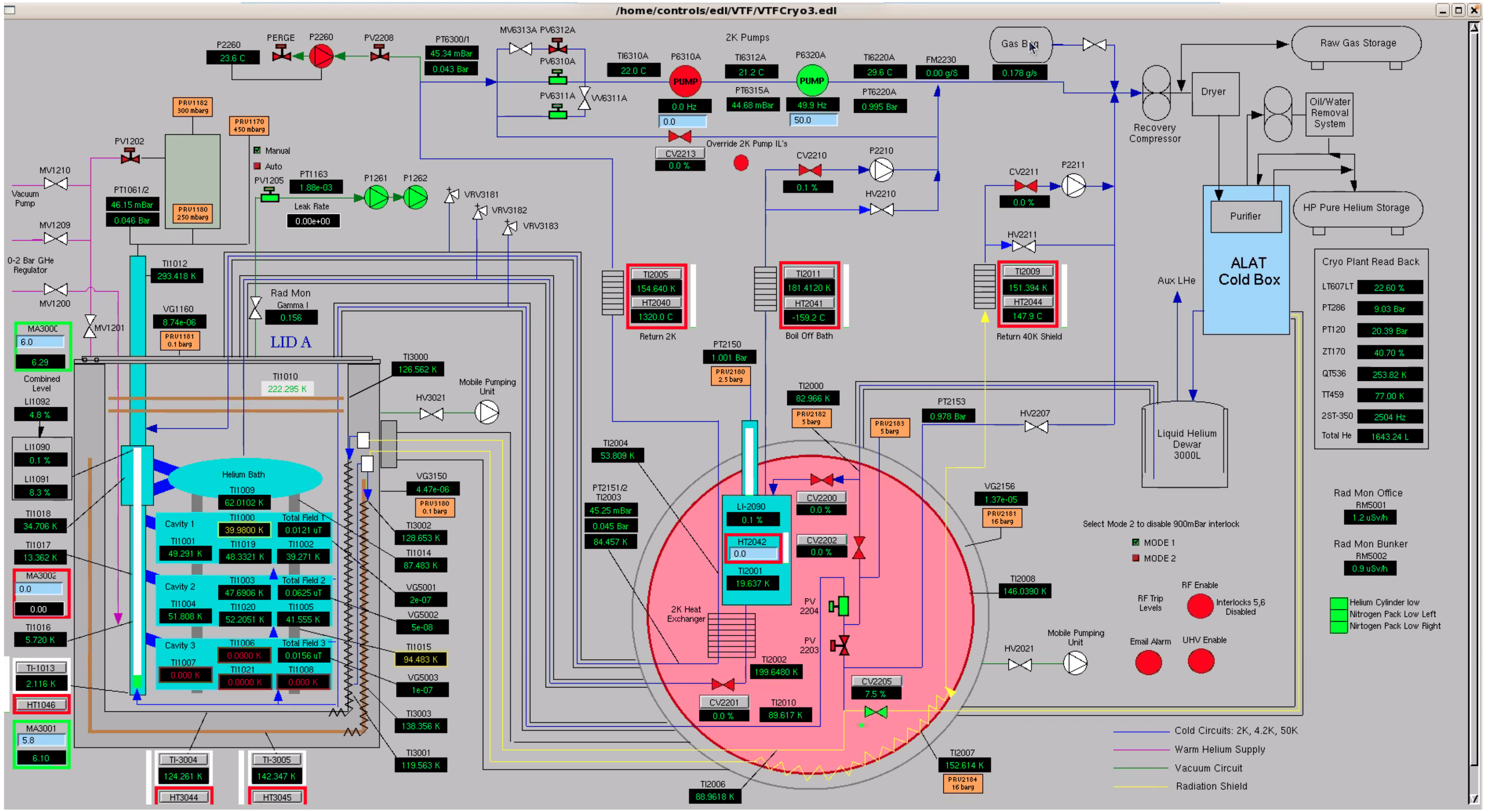


VTF Cryostat and Bunker

- Single Vacuum Chamber (IVC +OVC) in bunker
- Cryostat size: 4 meters deep by 1.7 meters diameter
- Total LHe volume for 3 cavities: 445L
- Top-up time ~2.5 hours
- Pump down time ~1 hour
- Speedy warm up by boiling off LHe and driving GHe through cooling circuits, ~72 hours



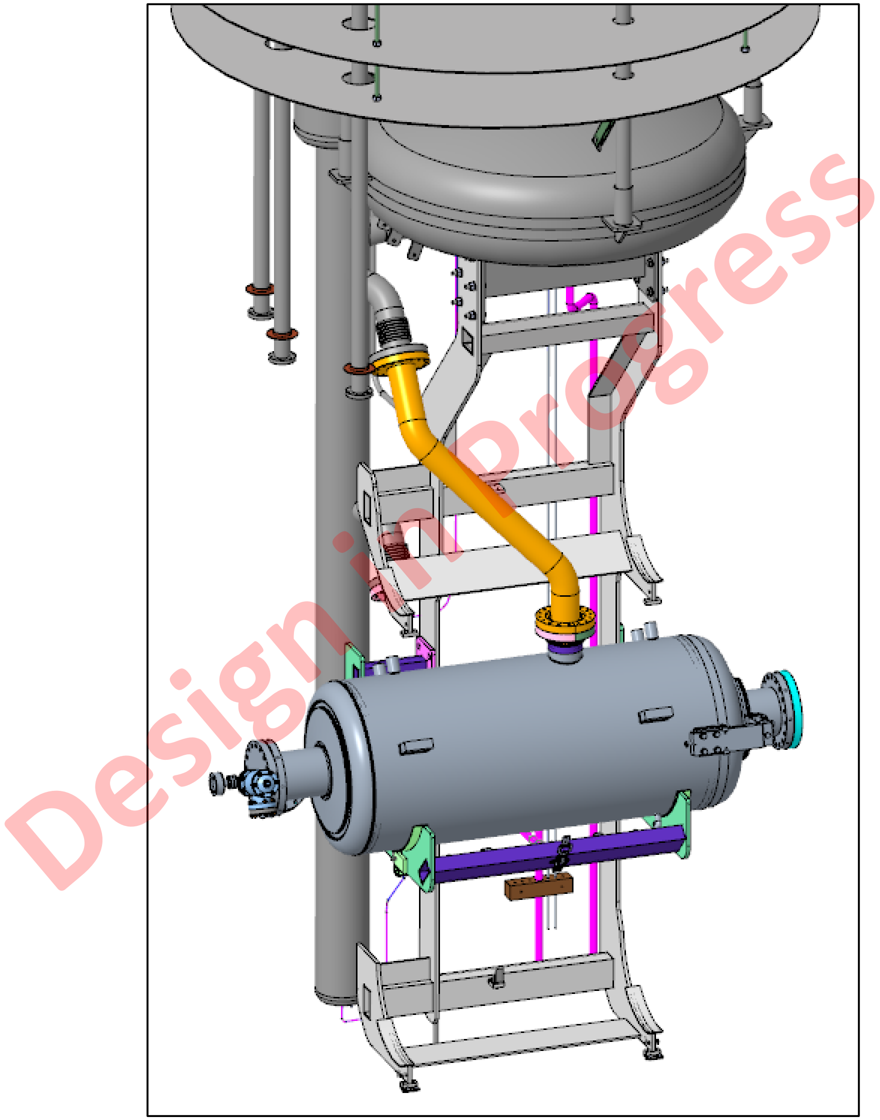
Cryogenic Infrastructure



- Recovery circuit - closed cycle
- 3000L LHe dewar
- PID control keeps pressure and temperature stable to ± 0.1 mbar and ± 1 mK
- 2k pumps give 25w of cooling power (upgrading to 50W)

CSI Modifications for PIP-II Cavities

- Larger cavity size
- Lowest magnetic field in middle position
- Faster cooldown rates through the superconductor critical temperature



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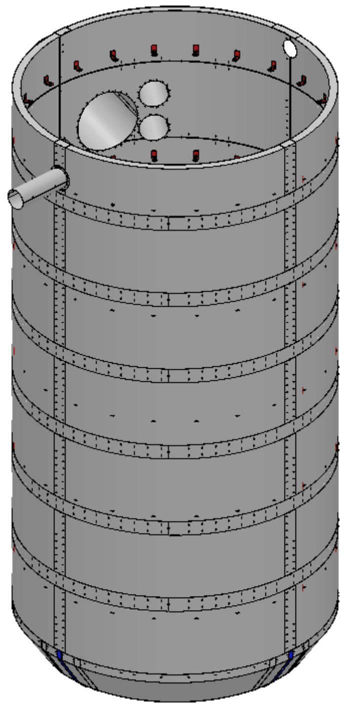
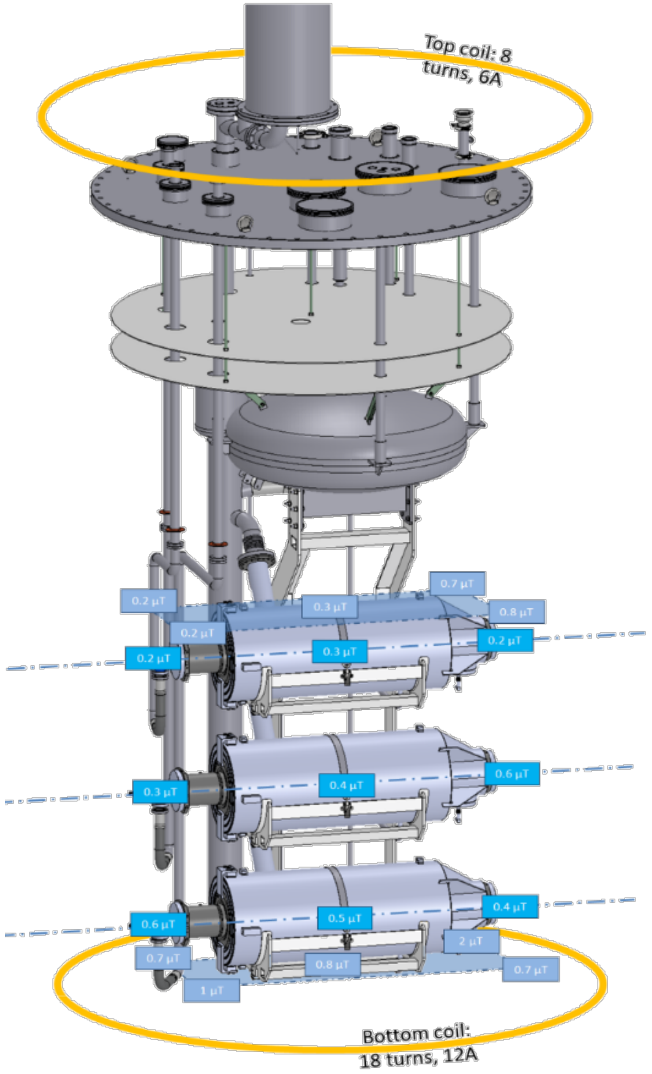
DESY

Magnetic Shielding



- Stray field attenuation to <1.4µT by static Mu-metal shield
- Further attenuation to < 1µT by two active coils
- Installation of Bartington 'Cryomag' field sensors for continuous monitoring of magnetic fields
- <0.5µT required for PIP-II testing



Ultrahigh Vacuum System

- 3 separate UHV lines
- Operates within 10e-7 range
- Custom slow-pump-slow-vent (SPSV) UHV system is built onto each CSI
- Cavities are actively pumped during RF testing

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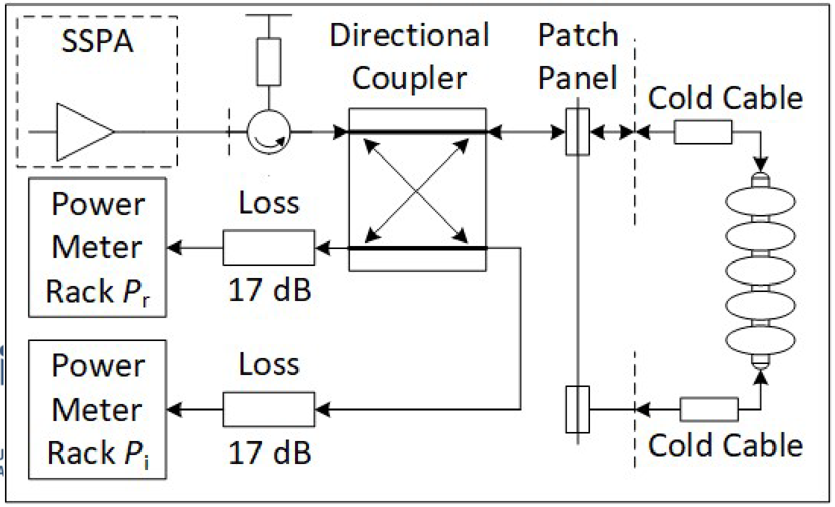
DESY

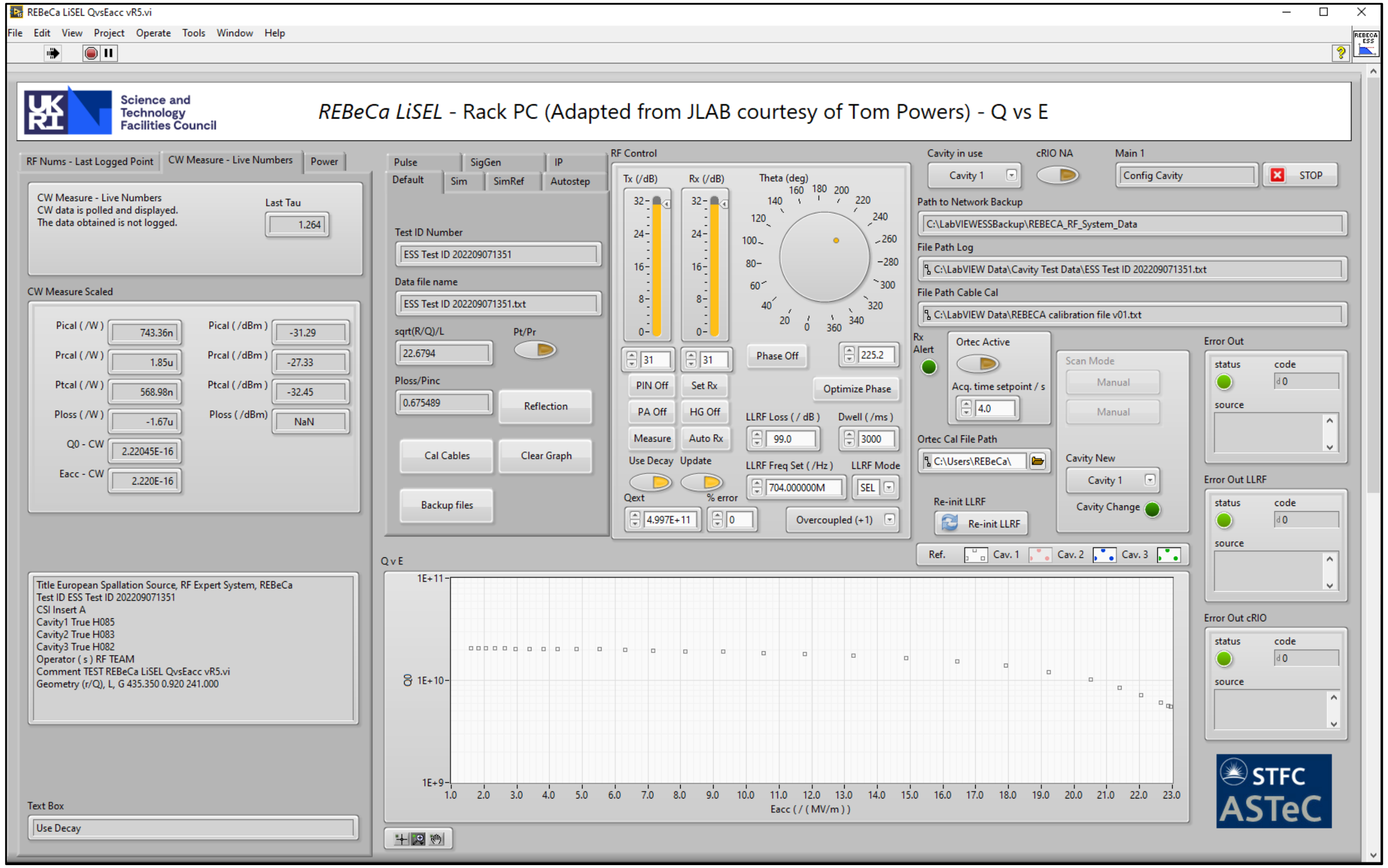
RF System

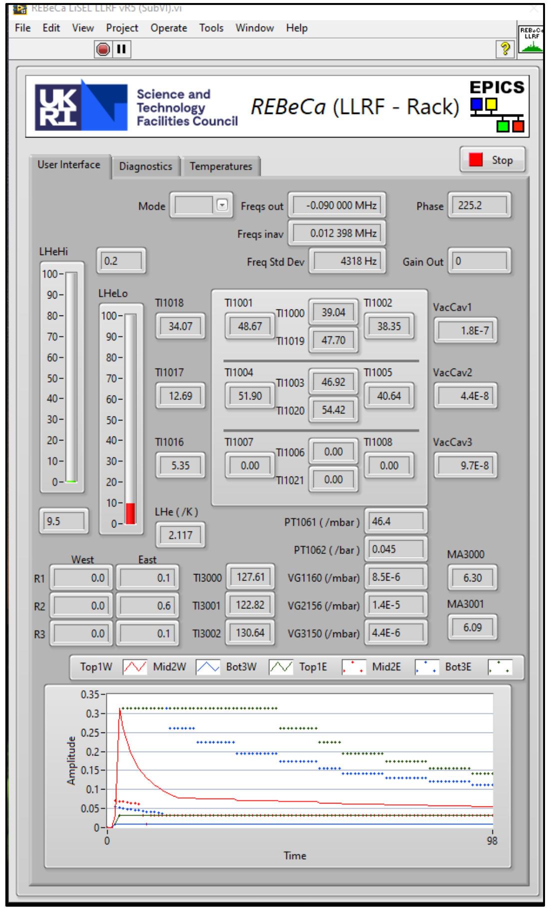
- 500w 704MHz Power Amplifier (ESS)
  - 200W Incident Power at Cavity
- 400w 650MHz Power Amplifier (PIP-II)
- Custom RF Electronics controlled with NI Compact RIO device.
- HP Circulators and directional couplers housed inside bunker



RF Controls

- Shows live numbers for power levels, radiation etc.
- Handles calculations and datalogging
- Automated routines to assist with calibration, phase setpoints, reflection measurements…

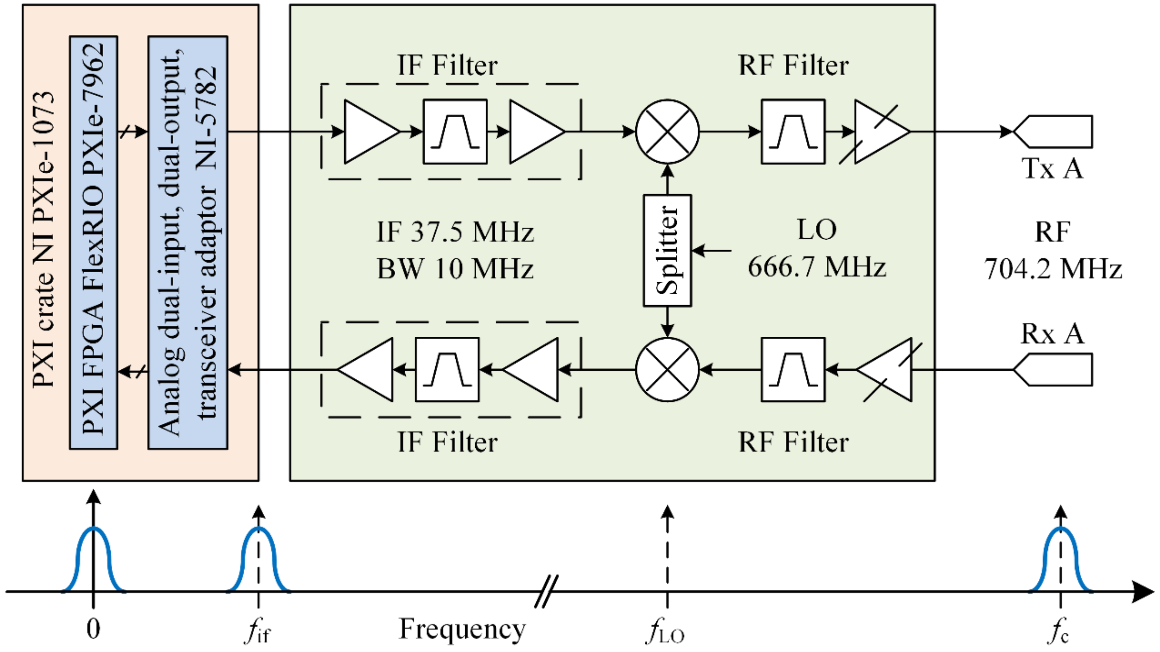


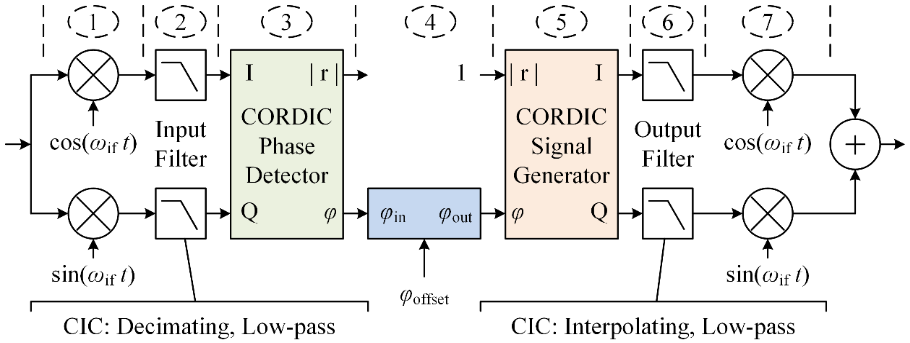


Based on the design by Tom Powers (Jlab) and developed by Keith Dumbell (STFC)

Low Level RF

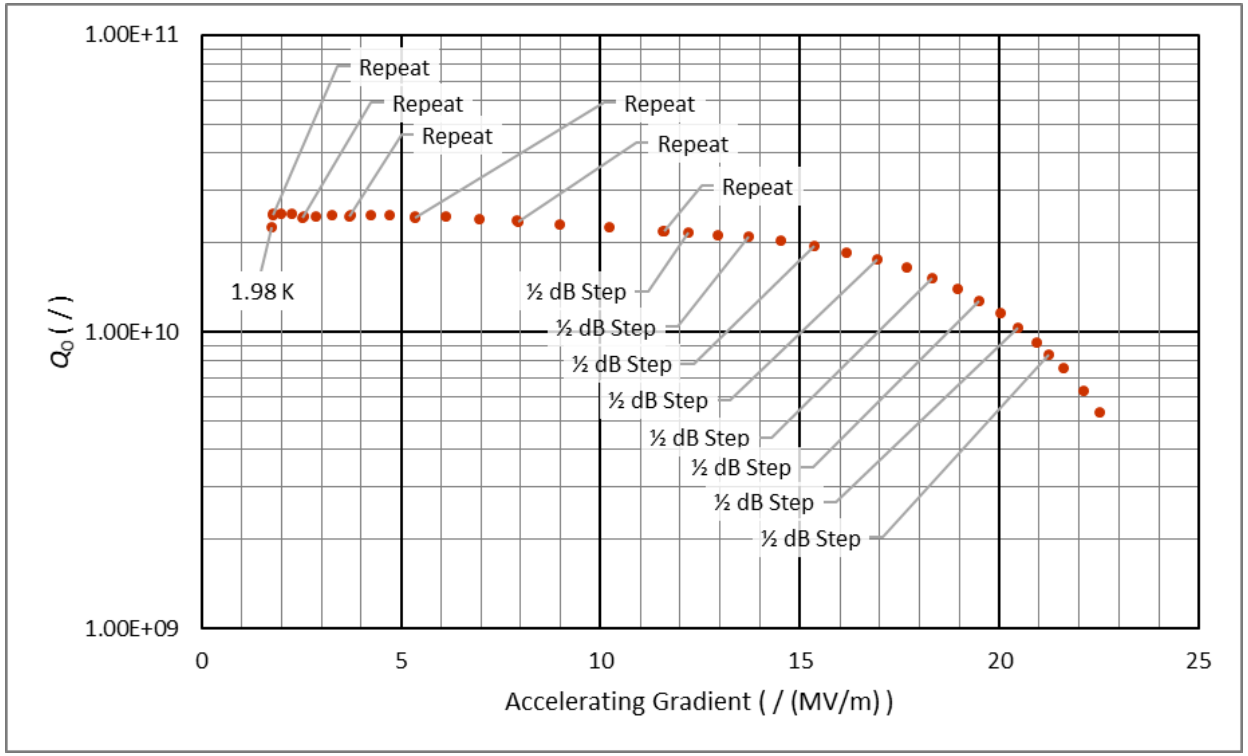
- Developed in-house for PIP-II and currently deployed for ESS
- Self Excited Loop implemented on National Instruments hardware
- Features: Lock detection, mode hunting, overload protection
- Scalable to other frequency ranges





K Dumbell *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1240** 012151

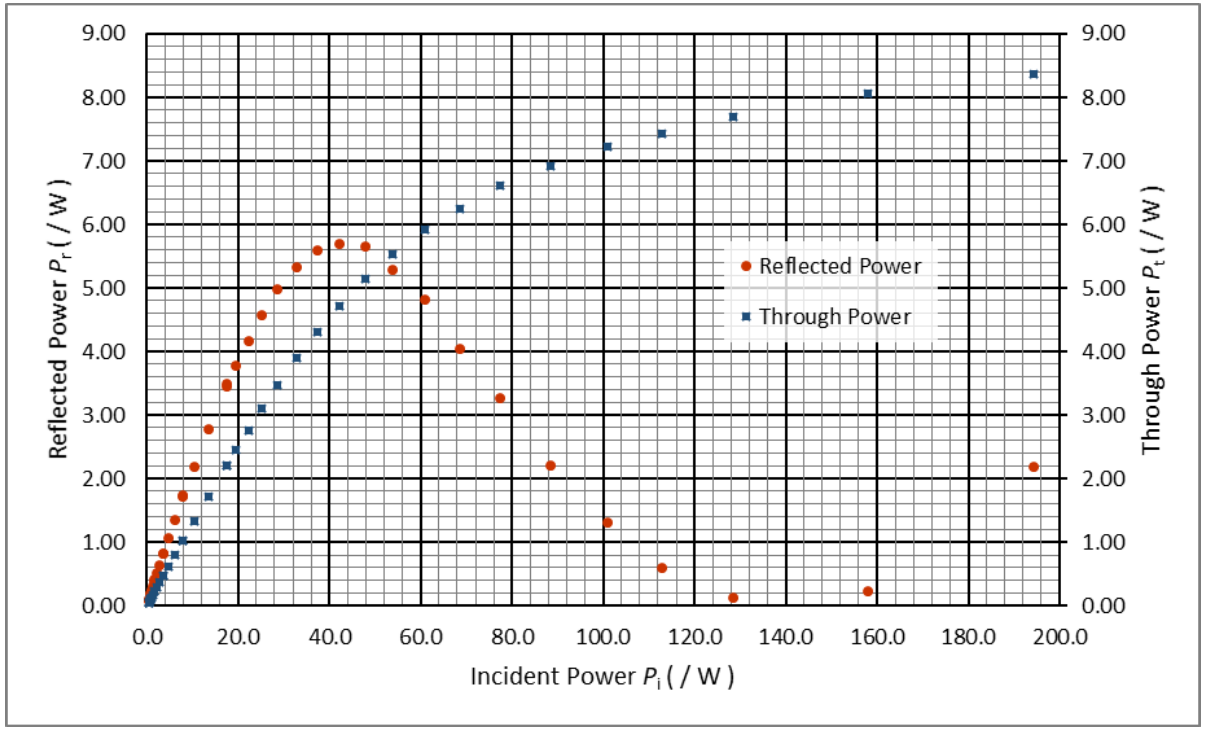
Q_0 vs E_{acc} curve



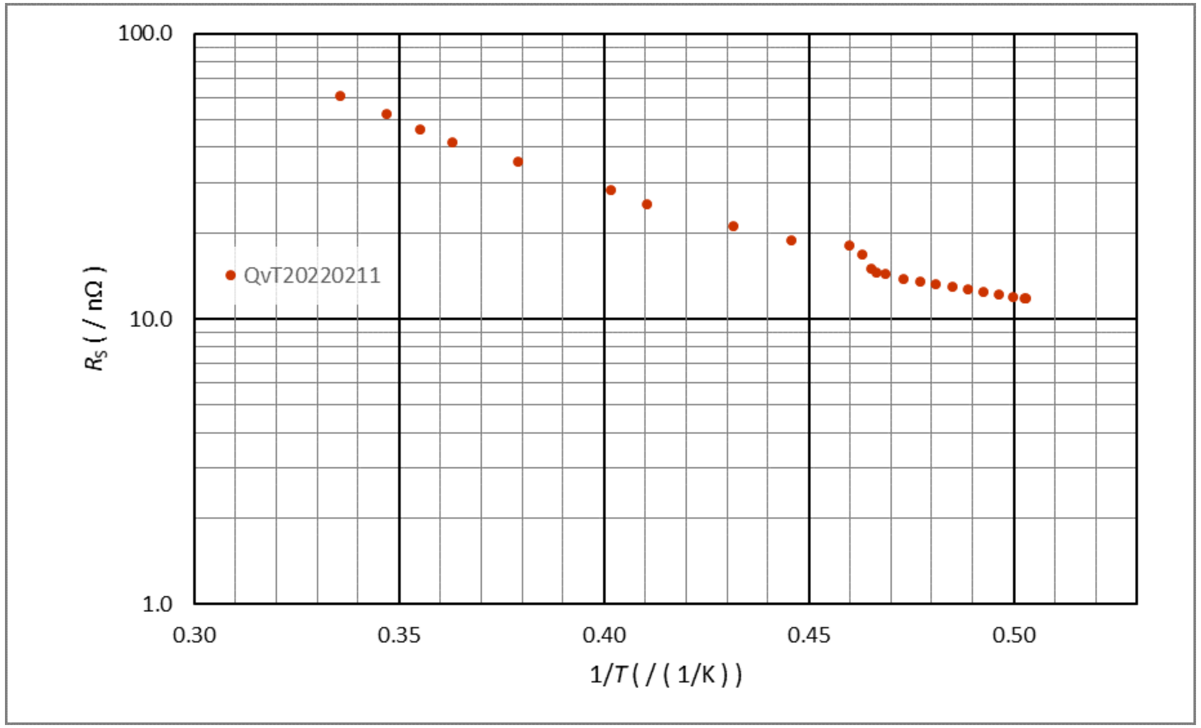
- New LLRF tested on production cavities, measurements made at ½ dB steps.
- The results were repeatable and followed a 'smooth' curve.

Power Relationship

- Insight into the suitability of the system can be gleaned by examining the reflected and incident power.
- The reflected signal provides an indication of effectiveness: less than 0.1% of incident signal when critically matched
- Shows exceptional tracking of microphonics and no spurious components



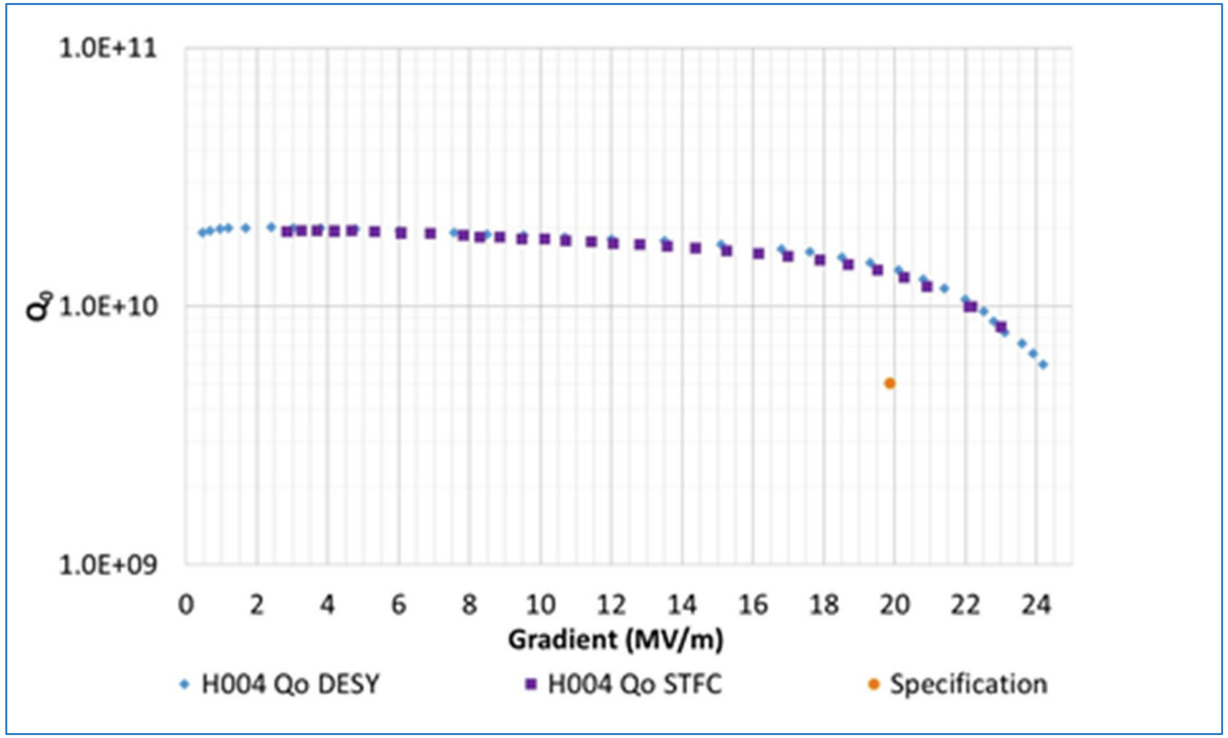
Q vs Temperature



- Q vs T can be made for RRR, hence determining the quality of the niobium.
- Requires careful planning and co-ordination between RF and Cryo teams
- Data acquired on 3 cavities simultaneously

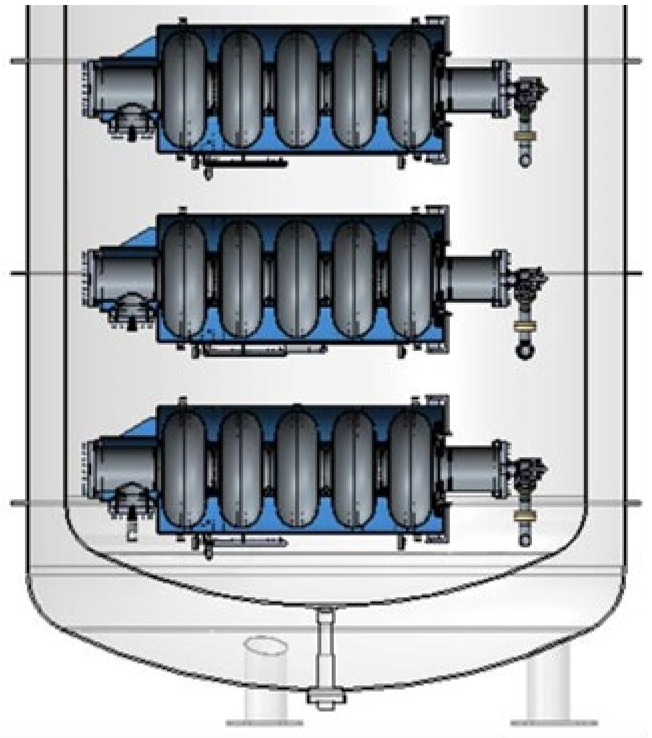
Validation of RF Measurement System

- The jacketed cavity H004 was measured at both STFC and DESY. The agreement for Q was remarkably good.
- Typical errors in Q and E would be expected to be around 15 to 20%

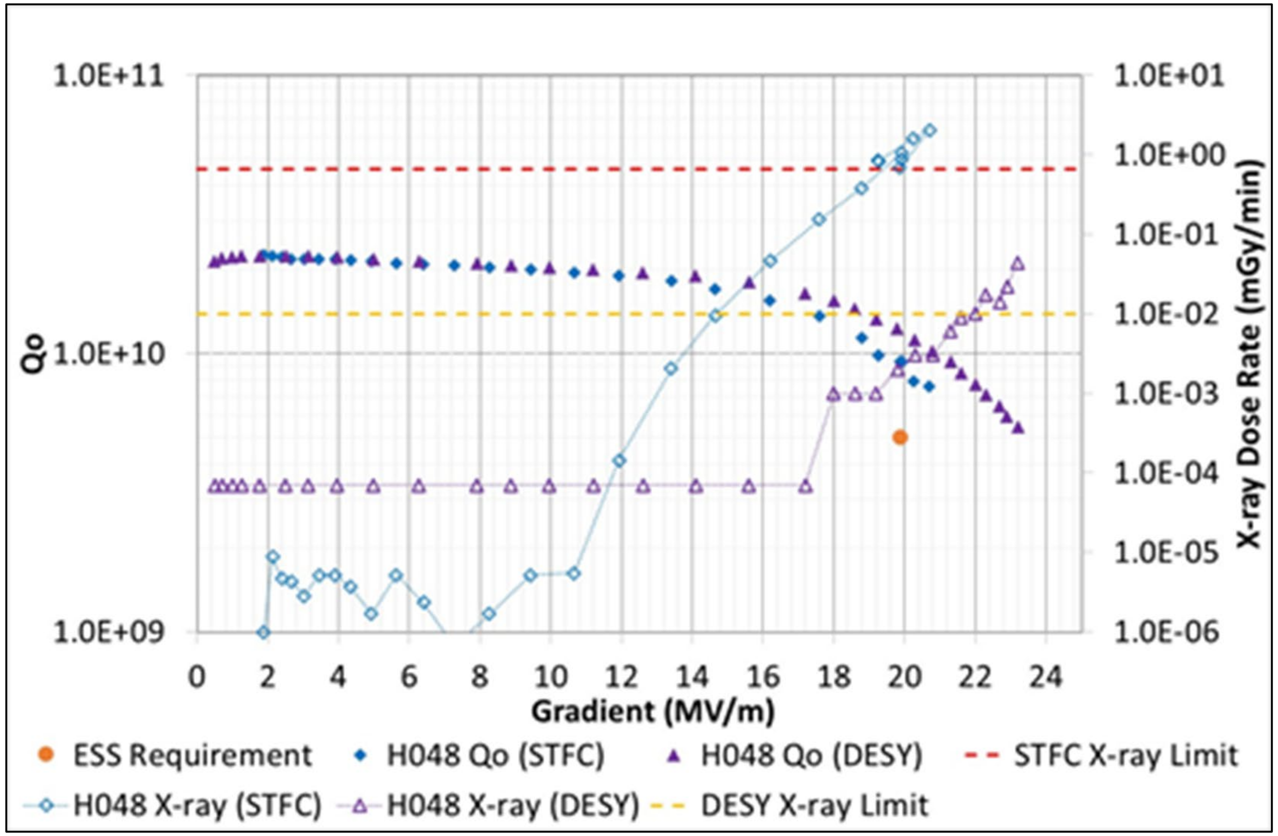


Radiation Measurements

- Mirion detector head placed on-axis to the cavities
- Saturation level 100mSv/hr
- Two additional detectors for PIP-II
- Ortec Energy spectrum detectors
- Very sensitive due to close proximity to the cavities
  - Coupler (left) ~25cm
  - Pick-up (right) ~30cm
  - Wall thickness 1-2cm



Radiation Measurements Cross-Comparison

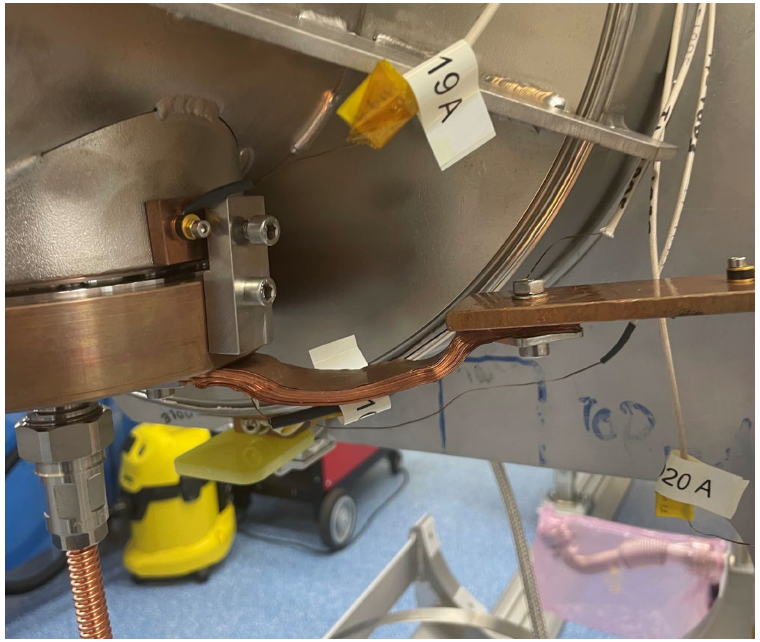


- H048 tested at DESY and STFC
- At the operating gradient of 19.9MV/m there is a factor of approx. 300 difference between the measurements.
- Onset of radiation was detected at approx. 12 and 17MV/m at STFC and DESY respectively

A Note on Cavity Conditioning

- Due to poor yield of ESS cavities we have higher failure rate and are investigating options with RF conditioning.
- System is designed to restrict LHe consumption, therefore RF cannot run CW at high powers.
- This facility is primarily designed for measurement system, we are still trying to understand the RF conditioning capabilities.
- We have been able to condition some cavities but others are much harder

Cooling the Input Coupler Flange



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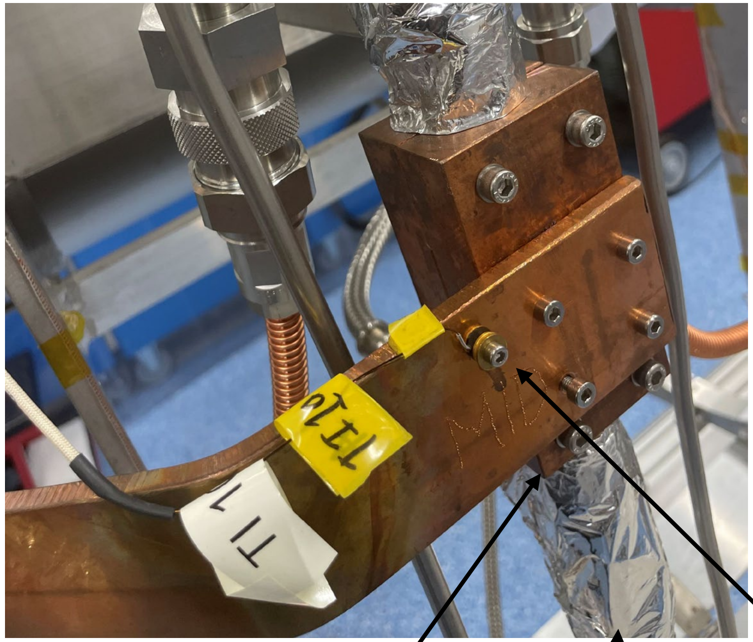


B

C

Copper Clamp (heat sink)

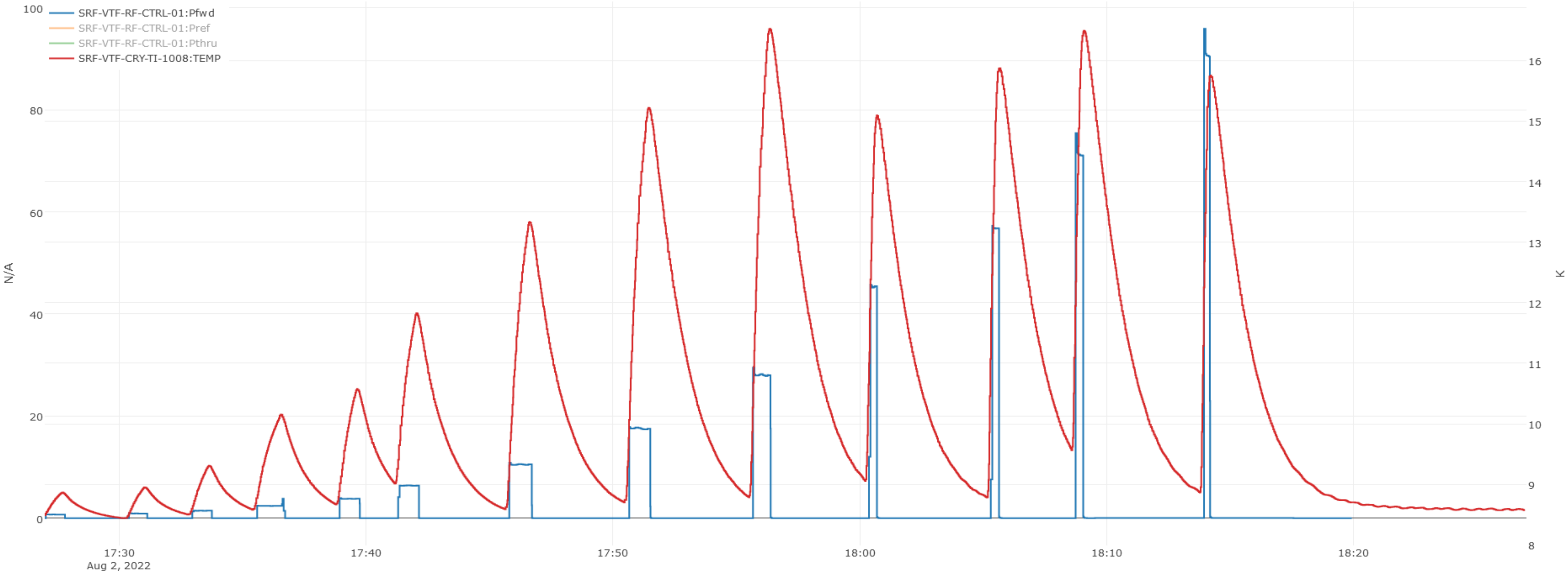
Bottom Fill line

Copper thermal strap

RF coupler flange thermal boss

Effect of Flange Temperature on RF Testing

- Settling time is heavily dependant on shield temperature
- Typically at Pi of over 150w for 40s, we wait ~5mins (<20% duty cycle, often <5%)



Points for discussion / ideas

- Fast pulsed RF to reduce average power dissipation in the cavity
- Amplitude modulation of RF drive signal

Daresbury VTF Summary				
No	**Property name**	**Value**	**Unit**	**Comment**
1	LHe volume	445	L	With 3 cavities loaded
2	Operating temperature	>1.9	K	
3	Diameter / size	1.7	m	
4	Number of inserts	2		
5	RF Frequency	638-655, 690-710	MHz	
6	Maximum Incident power	160 , 200	W	
7	Additional instrumentation	Radiation Dose rate and Energy Spectrum		
8	Typical testing rate (Vts / year)	19 (57)	Runs (Cavities)	Sept 21 – Sept 22
9	Possibility to test naked cavities	Not without significant upgrades to cryogenic infrastructure		
10	Infrastructure for small intervention		YES	

Thank You

Contributions from Andrew May, Paul Smith, Ayo Akintola, Conor Jenkins and Oliver Poynton

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Hints for table test stand summary

- Ad. 3 – In case cryostat is not round please put 3 dimensions here
- Ad. 5 – please write down all frequencies (or frequencies ranges) which can be measured in test stand
- Ad. 7 - Second Sound, T-mapping, B-mapping etc…
- Ad. 8 - Approximately or number of Vertical tests in 2021
- Ad. 10 – Please mark YES, if in your Lab there is a possibility to make some small changes in delivered cavity configuration (there is an additional clean room(s) and experienced personnel to make such intervention)