DQW Crab Cavity HOM evolution during manufacture and cold tests

Amelia Edwards on behalf Lancaster University, SY-RF-RF and HL-LHC WP4

13th HL-LHC Collaboration Meeting - Vancouver – 25th to 28th September 2023
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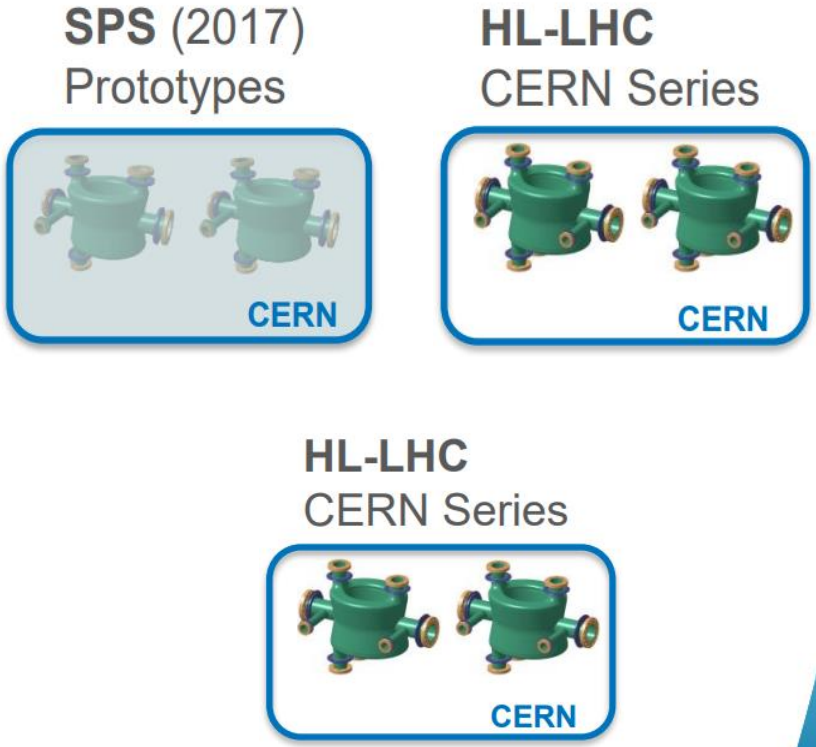
Introduction

- Cold test summary so far: x4 bare, x3 jacketed, x2 dressed
  - Frequency tracking of fundamental and HOMs throughout manufacture and testing at 2K
- **For acceptance of dressed cavity during cold test - measurements of HOMs at 2K to ensure they are below impedance thresholds**
- Results presented from vertical tests at 2K for CERN DQW1 & DQW2

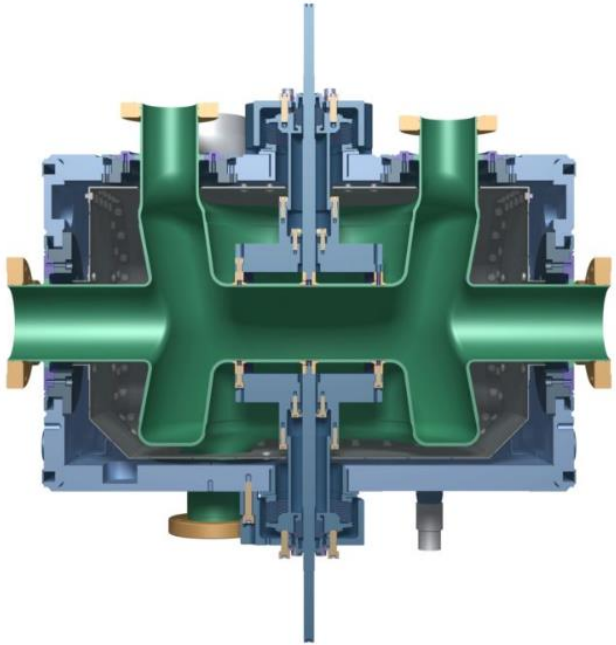


CRAB CAVITY HOMS DETAILS AND QUALIFICATIONS– (Reminder)

- The most important Higher Order Mode (HOM) frequencies to be tracked throughout manufacture
- From EDMS 2488213 –'*Crab Cavity HOMs Details & Qualifications*'
- High quality factors of these modes could be detrimental to LHC beam & infrastructure thus damping is required via dedicated couplers

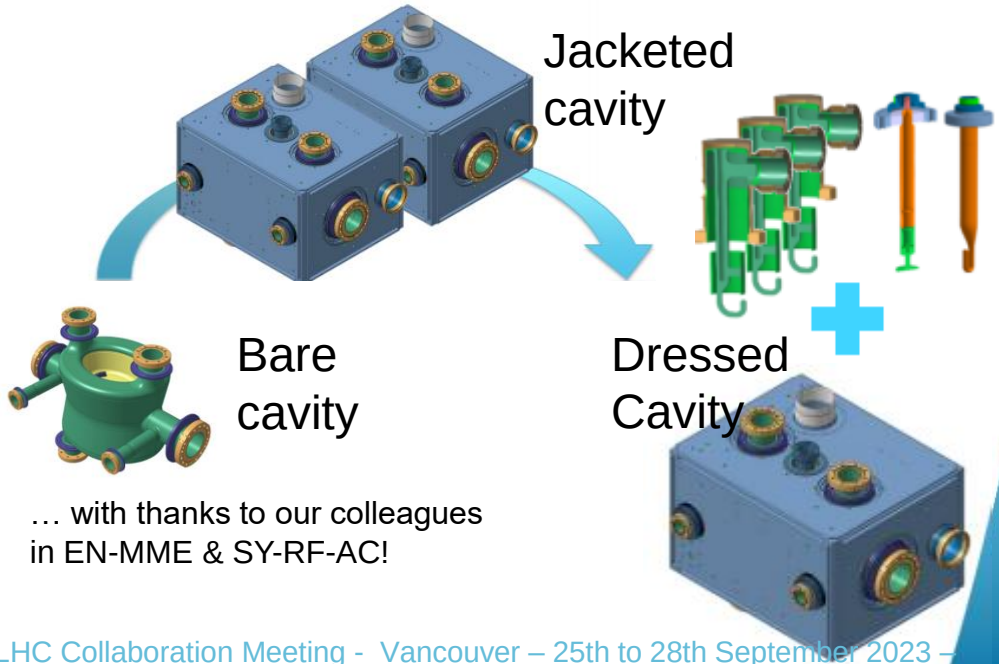
f [MHz]	Qe	$R_{\perp v}$ [kΩ/m]	$R_{\perp h}$ [kΩ/m]	$R_{\parallel}$ [kΩ]	Notes
582	1365	1	0	**73**	High power mode. Frequency is > 10 MHz from nearest bunch spacing harmonic.
683	580	0	**276**	0	
748	522	**156**	0	0	
927	845	0	**266**	0	
959	480	1	0	**4**	High power mode.
1496	2126828	0	**1137**	0	Mode over transverse threshold.
1500	17581	0	**874**	0	Damped by HF-HOMC. Mode over transverse threshold.
1584	3863	**57**	2	**31**	
1661	18343	0	**268**	0	Many modes near to this frequency.
1754	3791	0	**331**	0	Damped by HF-HOMC.
1922	24305	0	**953**	0	

Warm HOM Measurements:



Bare to Jacketed to Dressed

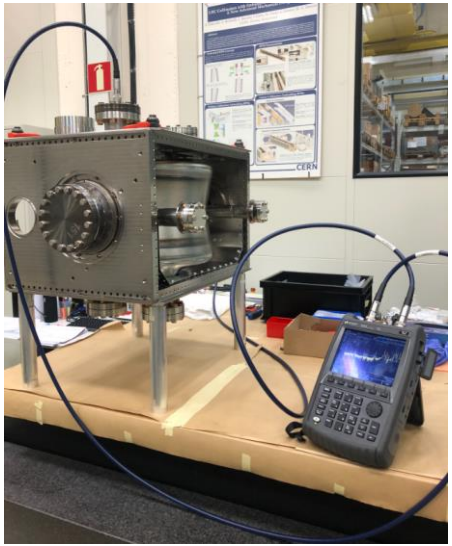
- Since BC test results, x2 cavities jacketed at CERN and x2 at RI
- Fundamental frequency measurements taken during jacketing to ensure no disturbance to the bare cavity
- At CERN, the HOM frequencies are also monitored through this process



… with thanks to our colleagues in EN-MME & SY-RF-AC!

DQW Jacketing – Warm HOM Measurements

- Fundamental frequency tracking covered by N. Valverde
- S21 taken between beam pipe and FPC using warm antennas
- No significant frequency shifts and small standard deviation (on the order of kHz) indicate no issues during jacketing



	CERN DQW1	CERN DQW2
HOM	**Mean Freq (MHz)**	**Mean Freq (MHz)**
580	581.780 ± 0.046	580.699 ± 0.067
699	700.680 ± 0.079	699.827 ± 0.045
745	745.866 ± 0.079	745.414 ± 0.037
959	959.836 ± 0.040	959.284 ± 0.056
1539	1530.937 ±0.091	1530.056 ± 0.158
1583	1581.446 ±0.019	1581.165 ± 0.043

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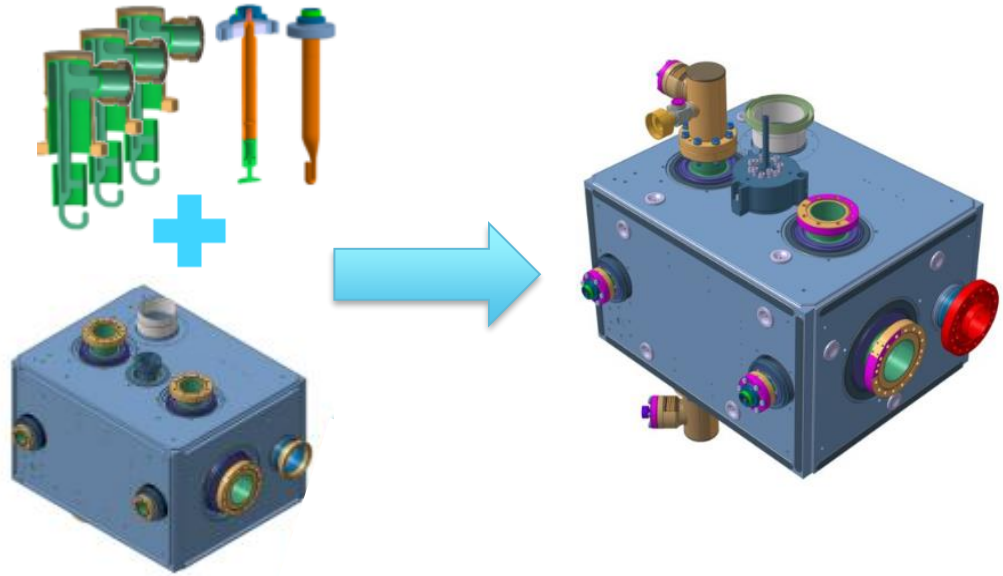
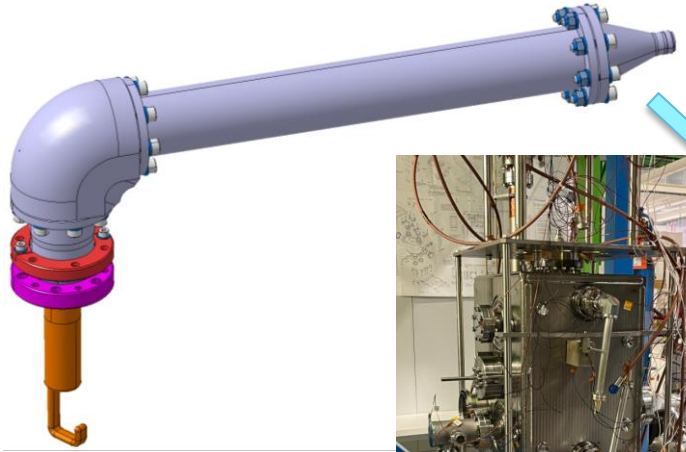
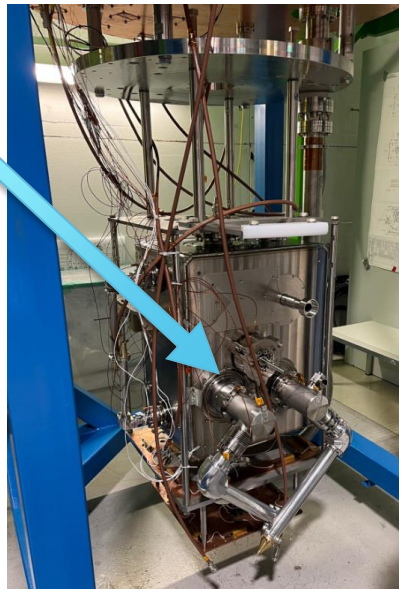
Dressed Cold Test Results:

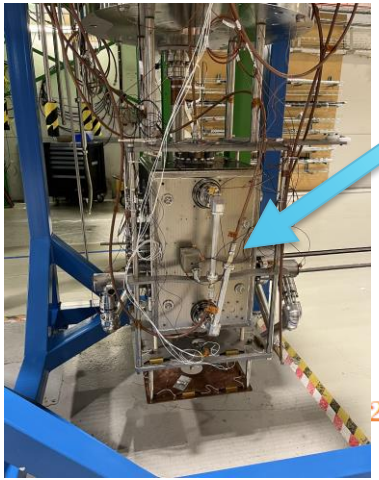


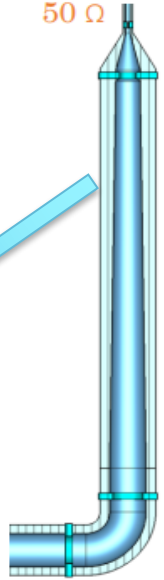
25 Ω to 50 Ω Adapters for HOMs

- 25 to 50 Ω adapters designed to qualify the HOM couplers and antennas before and after installation onto the cavity.
- Verified before cold test by TDR measurement and s-parameter measurement





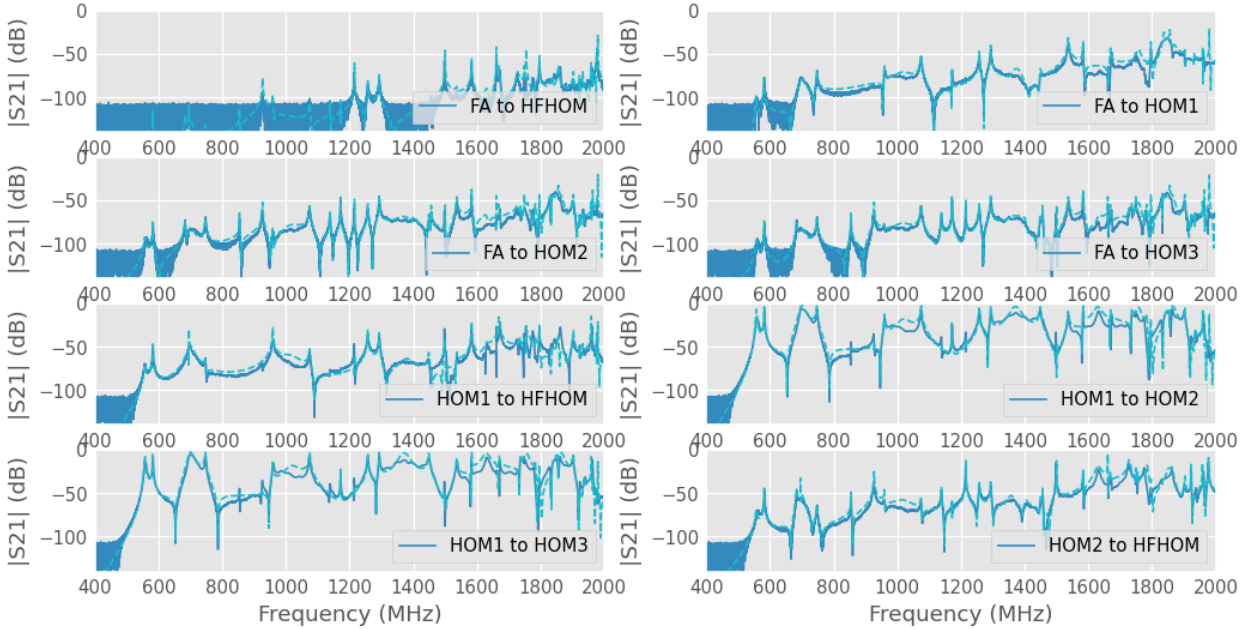


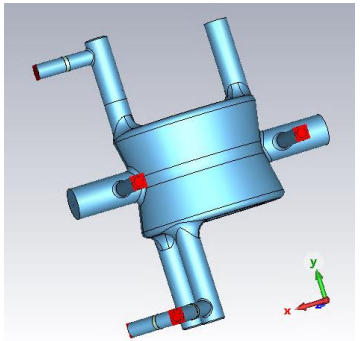


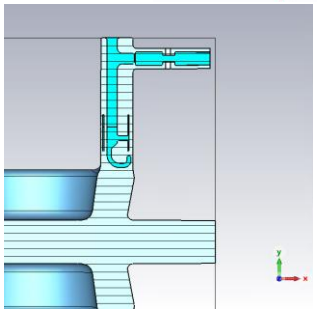
… special thankyou to Sebastien Calvo (SY-RF-AC)

CERN DQW1 DRESSED
Transmission Measurements

- S21 measurements taken between the ancillaries at 300 K and 2 K – Agrees very well with simulations!
- 5 ports with couplers (HOM1, HOM2, HOM3, HF-HOM, FA) plus the beam port antenna used for cold tests in SM18
- 8 port configurations measured to measure all modes.
- Measurements taken at 300 K and 2 K
- **Detailed studies ongoing and following up with 2nd cold test**







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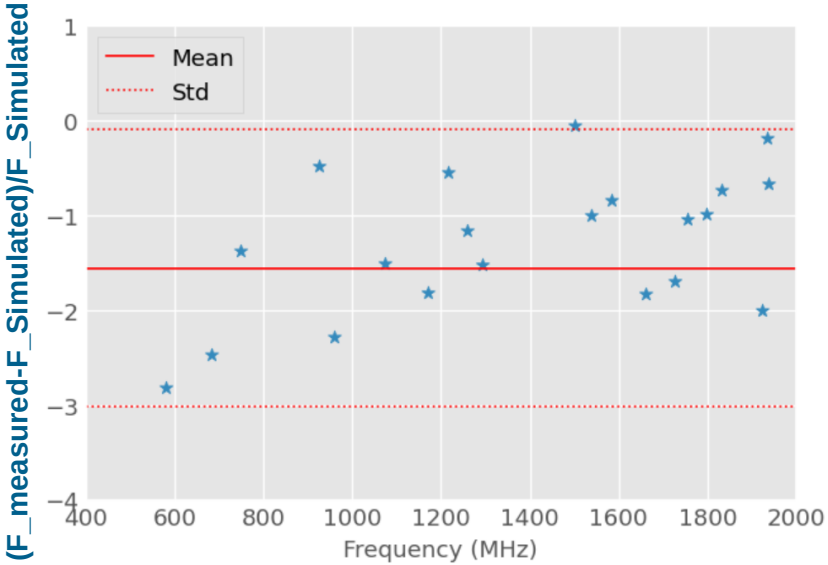
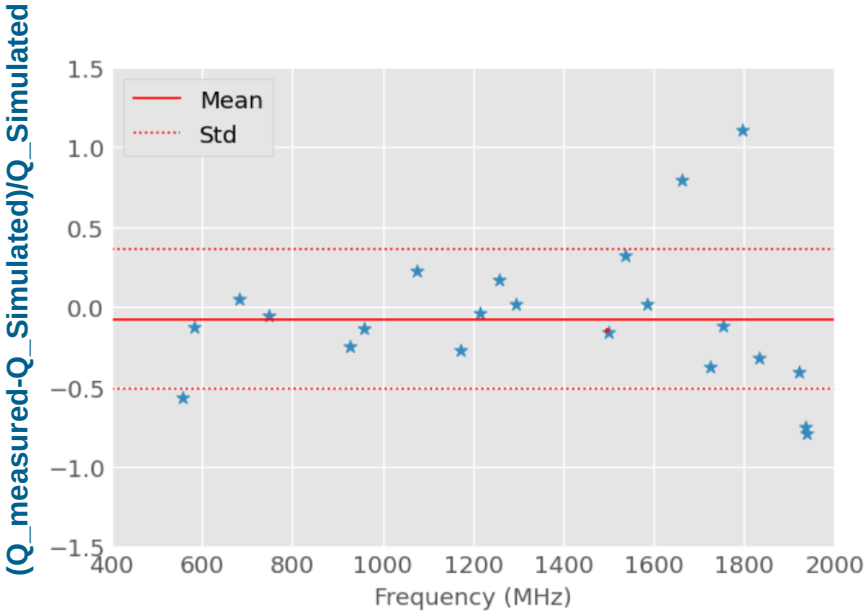
CERN DQW1 Dressed - HOM Frequencies at 2K

Comparison of measured HOM frequency and Q with simulation
Another cold test is scheduled for October 2023



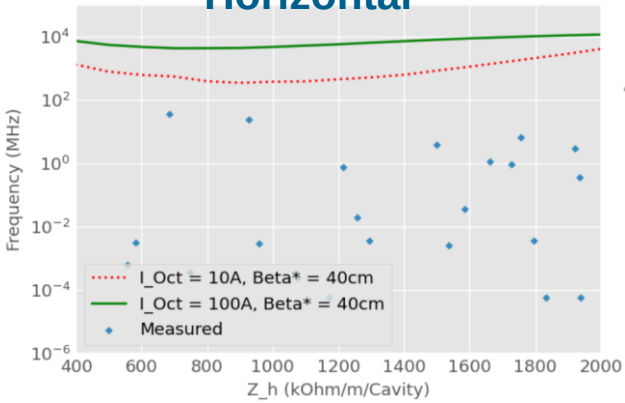


Freq	Q
-1.558 ± 1.458	-0.0748 ± 0.439

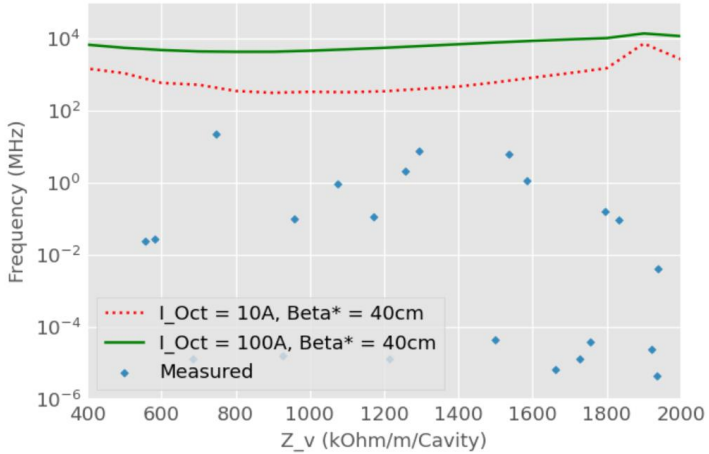
CERN DQW1 - Dressed Impedance

- Dressed test of CERN-DQW1-DC
- **Not final measurements, further testing upcoming**
- Measured results satisfy the impedance thresholds
- Impedance threshold proved by ABP
- Difficulty measuring 710MHz & 1495MHz (see extra slides)

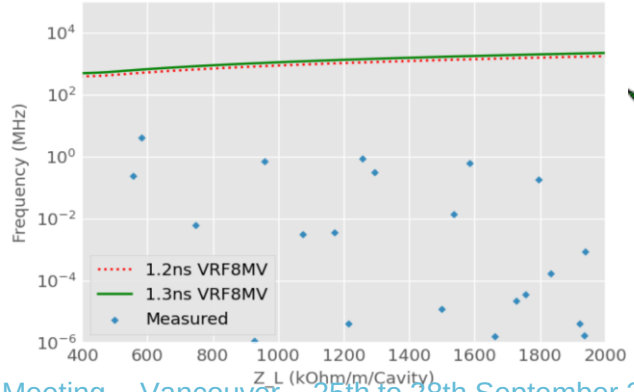
Horizontal



Vertical



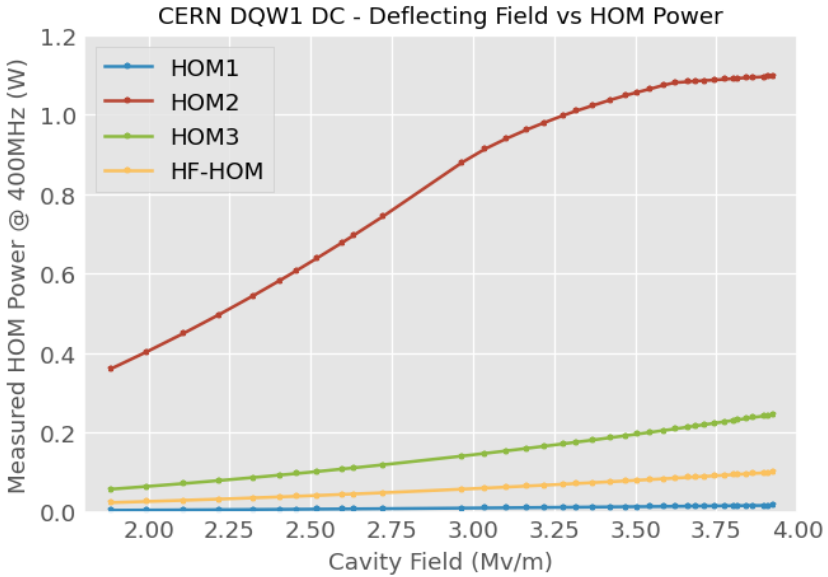
Transversal



CERN DQW1 DRESSED
Fundamental mode power leakage

- HOM couplers designed as band-stop filter at the cavity fundamental frequency
- During dressed cold test very low power leakage measured through HOM couplers

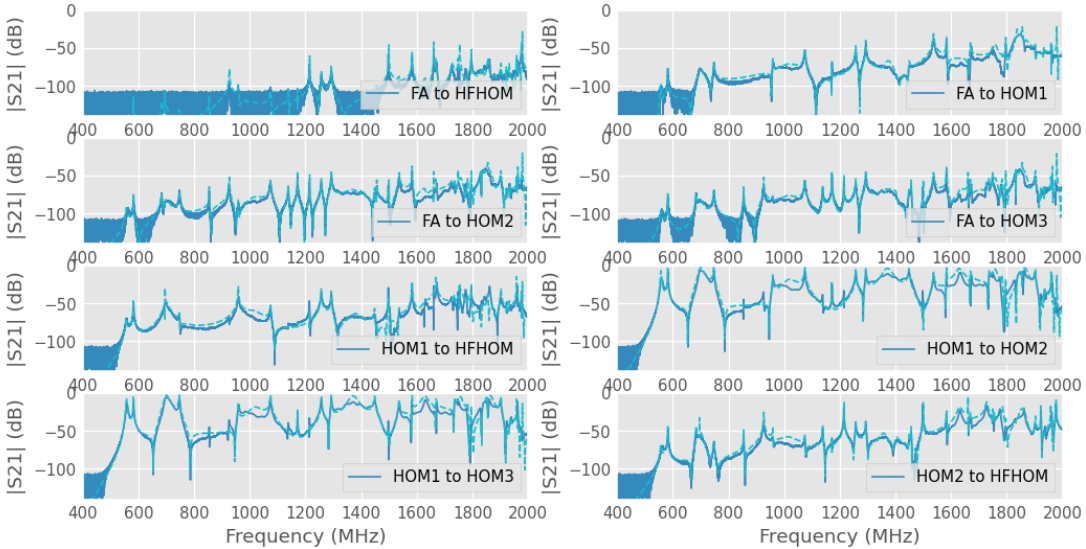
	Power @ 400MHz during CW Scan at 4.1MV/m	
HOM1	0.016W	✓
HOM2	1.097W	✓
HOM3	0.246W	✓
HF-HOM	0.099W	✓



Acceptance Criteria: Power @ 400MHz ± 0.15, VT = 4.1MV < 6.7W (EDMS 2488213)

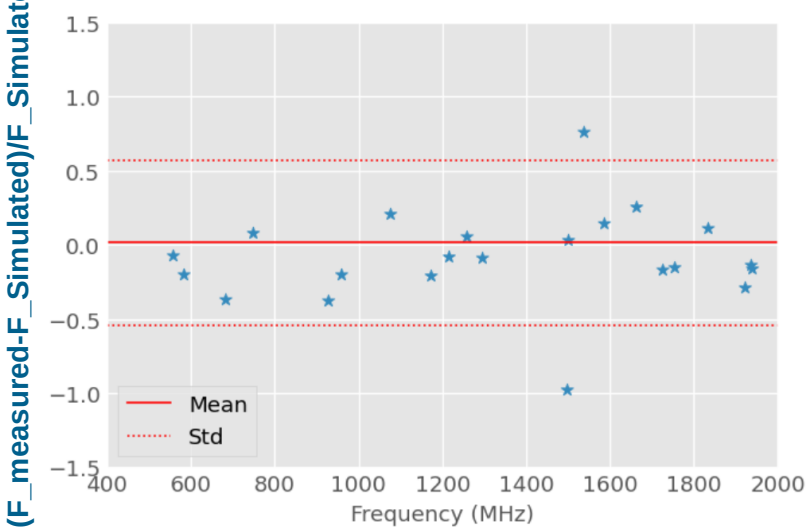
CERN DQW2 DRESSED Transmission Measurements

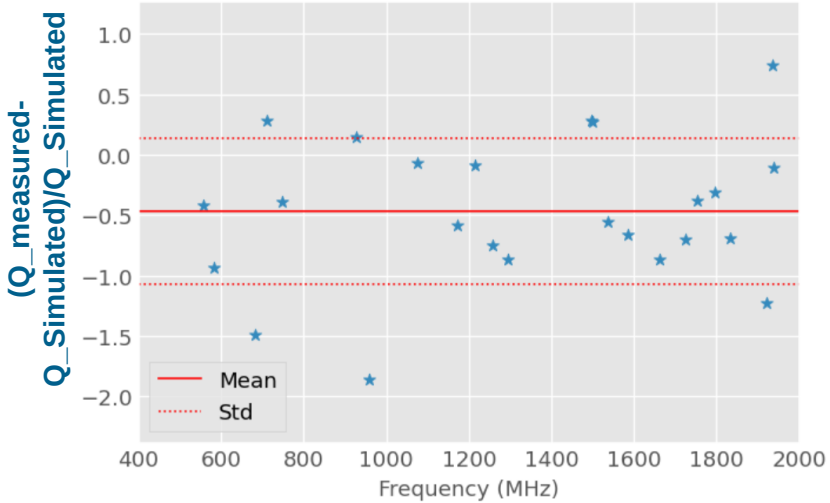
- More complicated than RFD due to the number of couplers
- S21 measurements taken between the ancillaries at 300 K and 2 K – Agrees very well with simulations!



CERN DQW2 Dressed - HOM at 2K

Comparison of measured HOM frequency and Q with simulation in CST to quantify deviations



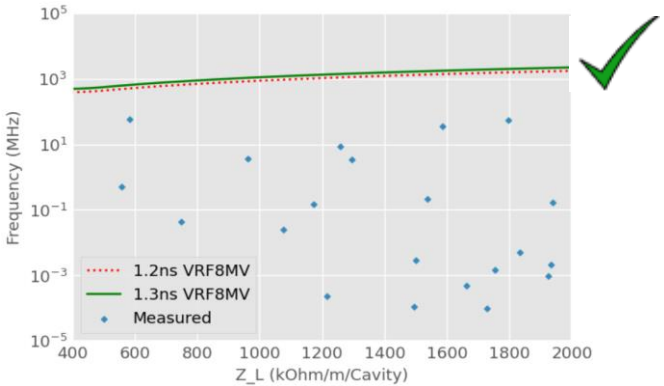


	Freq Deviation	Q Deviation
DQW2	**-0.468 ± 0.602**	**0.0147 ± 0.553**
DQW1	-1.558 ± 1.458	-0.0748 ± 0.439

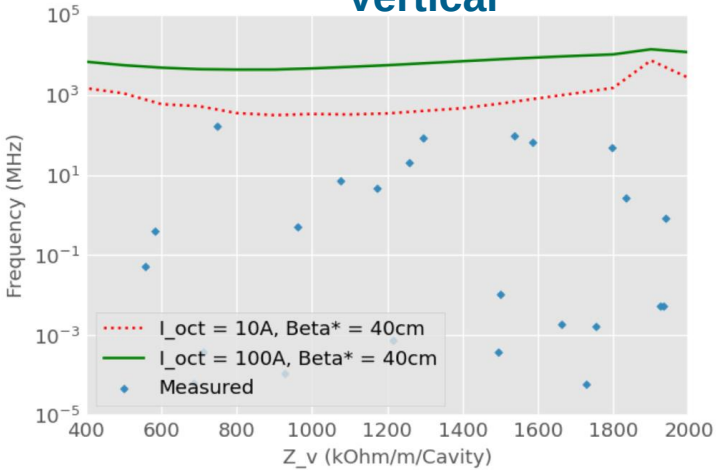
CERN DQW2 Dressed - Impedance

- Final test of CERN-DQW2-DC
- Measured results satisfy the impedance thresholds
- One mode over threshold

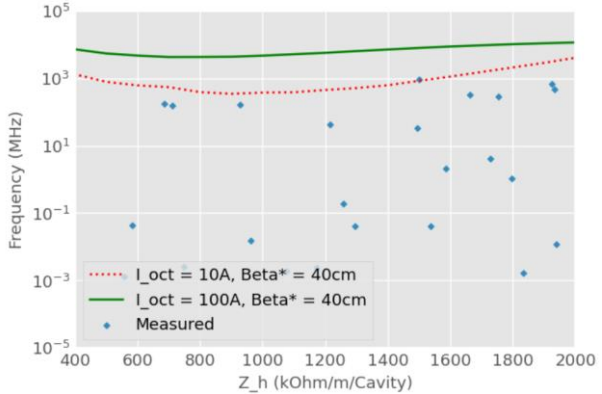
Horizontal



Vertical

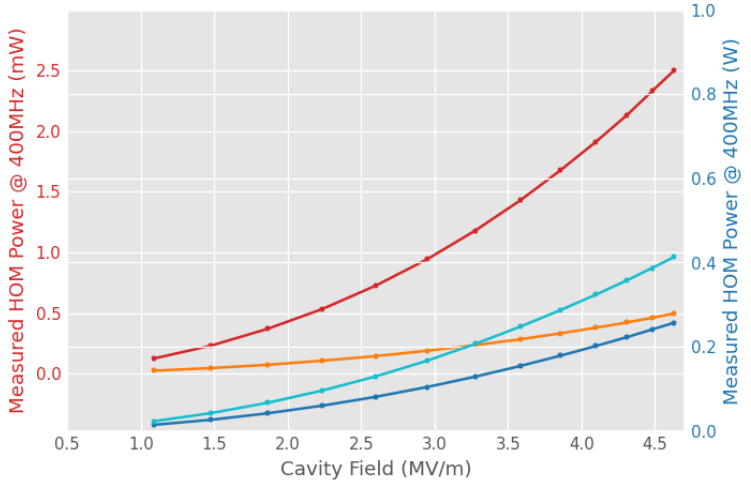


Transversal



CERN DQW2 Dressed Fundamental Mode Power Leakage

	Power @ 400MHz and 4.1MV
HOM1	19.66mW
HOM2	0.399mW
HOM3	0.202W
HF-HOM	0.324W

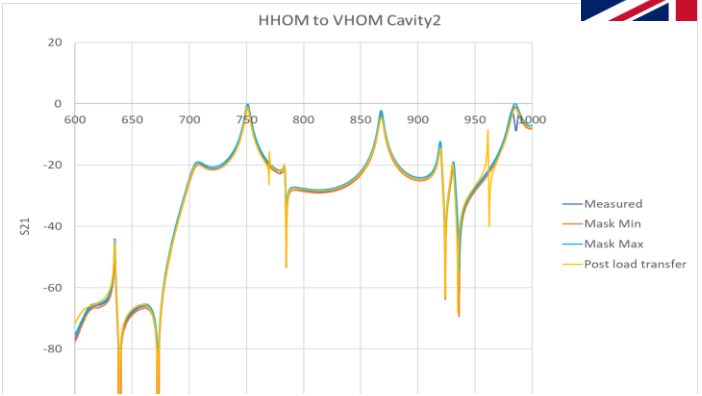


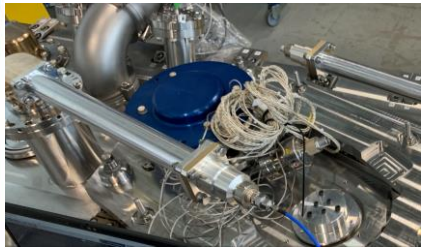
- **Final test of CERN-DQW2-DC**
- As with previous cavity, very low power leakage of the fundamental mode via the HOM couplers
- Power leakage increases with cavity field, thereby validating that the measurement is working

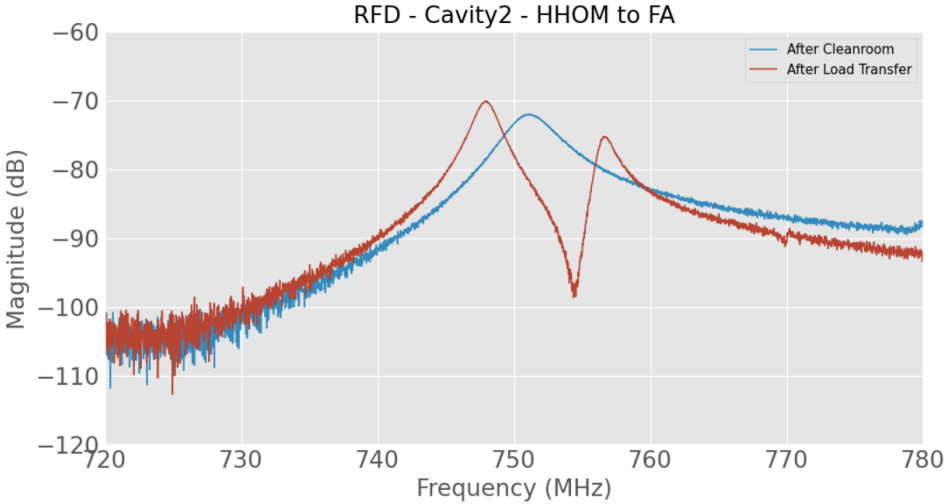
Acceptance Criteria: Power @ 400MHz ± 0.15, VT = 4.1MV < 6.7W (EDMS 2488213)

RFD Cryomodule…Warm Measurements

- Measurements taken at warm during cryomodule assembly (courtesy of G. Burt)
- There is almost no change between the measurements of the cavity string post-cleanroom and post-load transfer when measuring HHOM-VHOM up to 2 GHz
- The 750 MHz mode is split in two in measurements involving the field antenna, but 400 MHz signal is fine







Summary

- Measurements of HOMs during jacketing indicated no issues and consistent results from four cavities
- Dressed cold tests of two cavities, HOM measurements taken at 300K & 2K
- **Overall HOM measurements from both DQW1 and DQW2 dressed cold tests satisfied impedance thresholds & leakage of fundamental mode**
- Another test of DQW1 dressed cavity upcoming, more HOM measurements to be taken

Lancaster University

Thankyou!

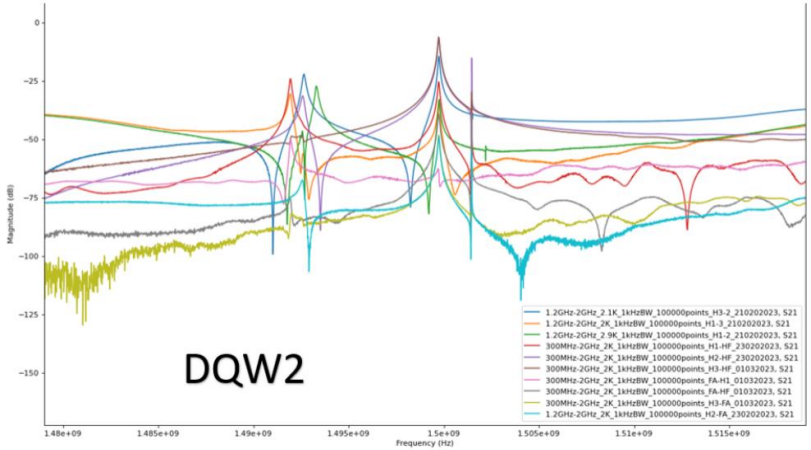
CERN

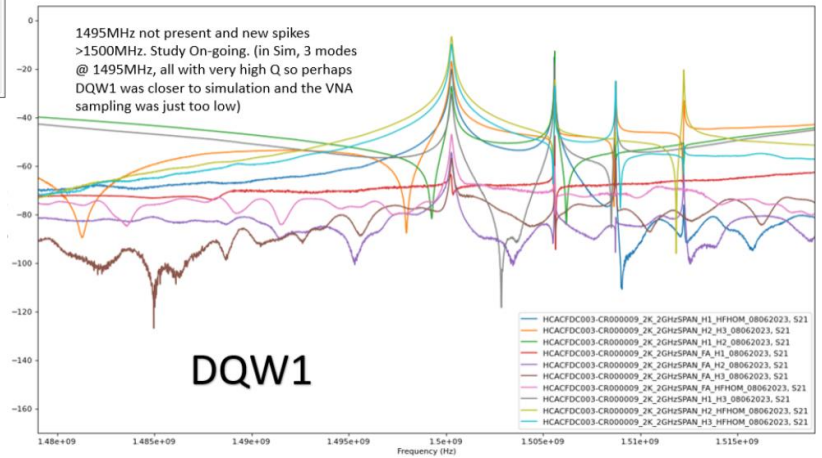
Lancaster University

Extra Slides

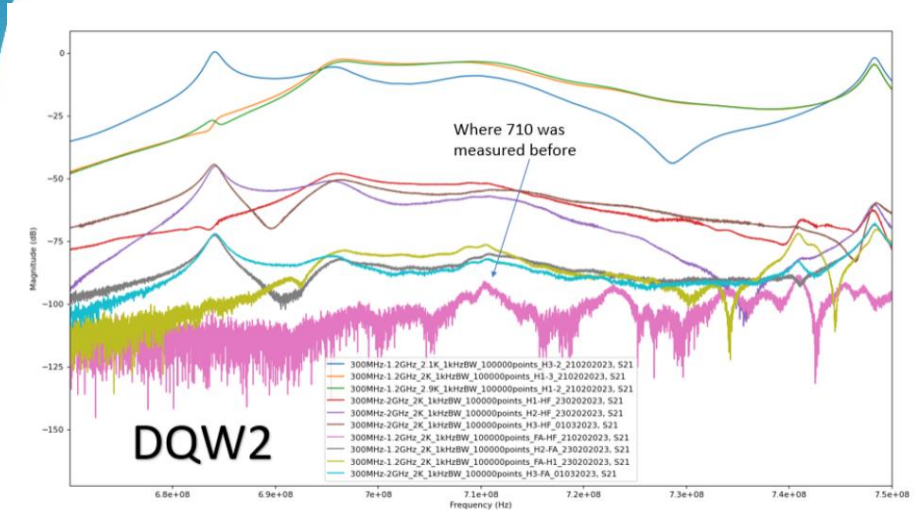
CERN

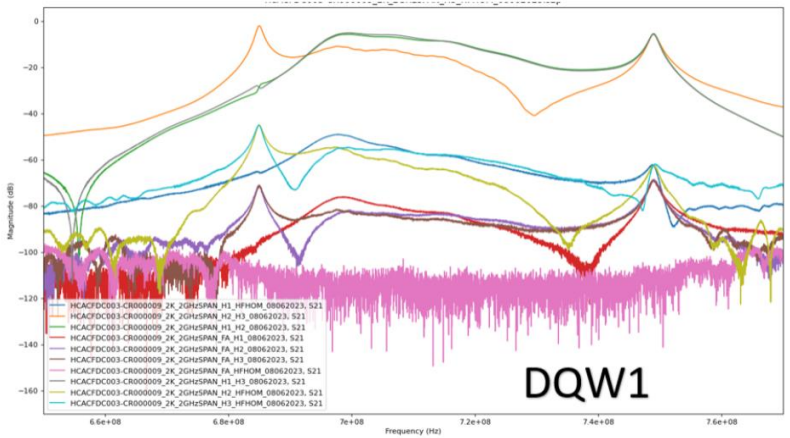
DQW Dressed Cold Test - 1495MHz



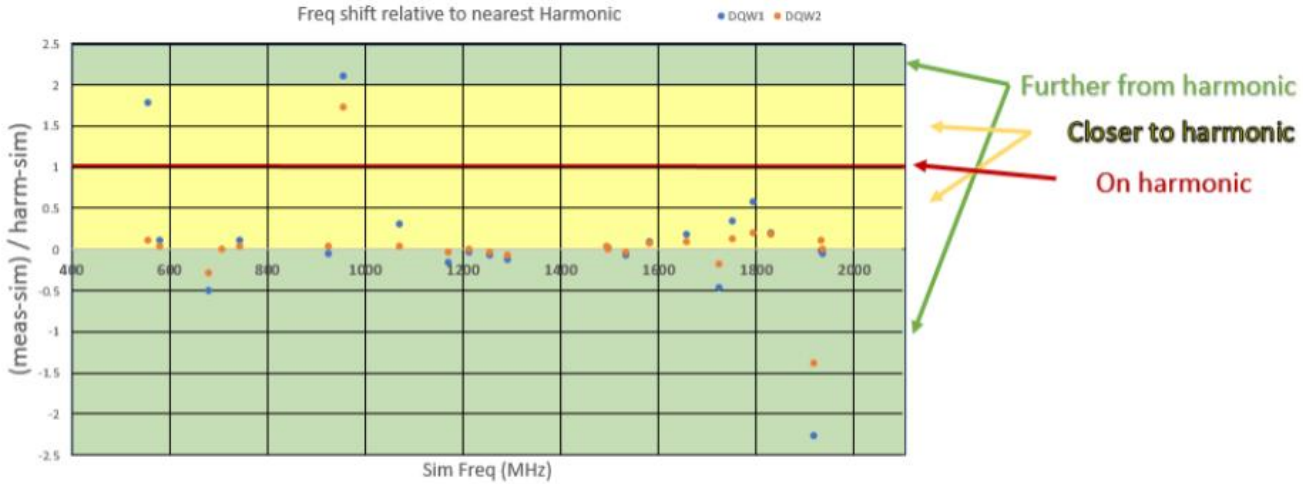


DQW Dressed Cold Test - 710MHz





CERN DQW1 Dressed – Movement of Harmonics



$$\begin{cases} y < 0 = moved\ away \\ 0 > y > 1 = moved\ towards \\ y = 1 = exactly\ on\ harmonic \\ y > 1 = moved\ other\ side\ of\ harmonic\ (better\ now\ if\ y > 2) \end{cases}$$