DQW industrial production & cavity assembly challenges

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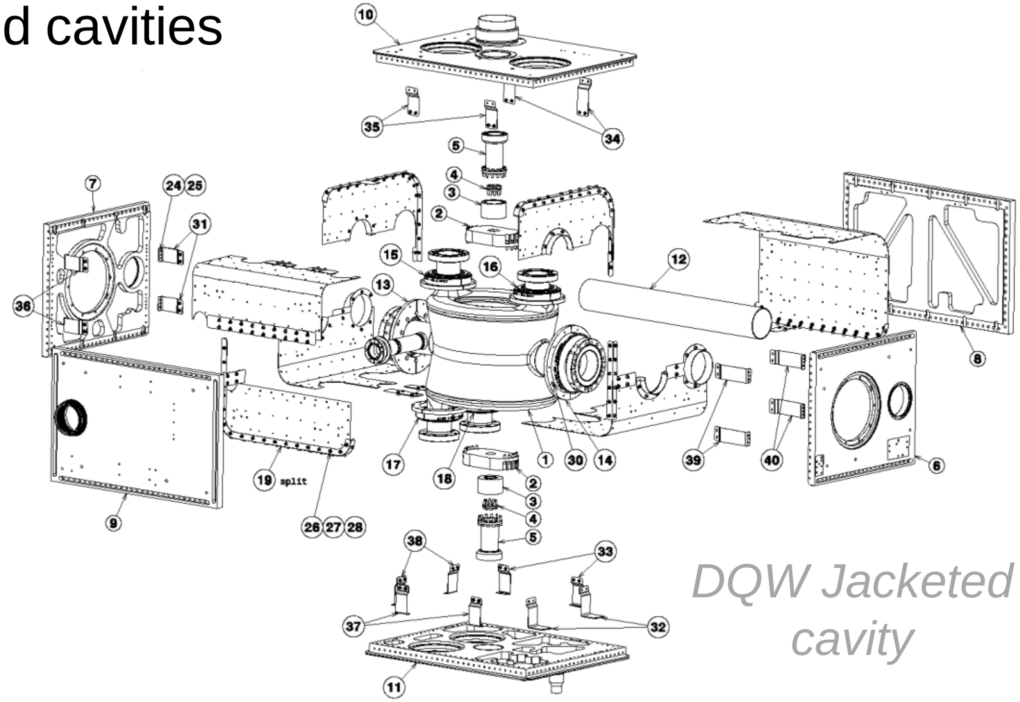
13th HL-LHC Collaboration Meeting, Vancouver, 27.09.2023

DQW Jacketed Cavities Contract

- Contract signed on March 2018 with the company Research Instruments (RI) to provide:
    - 1 preseries Jacketed cavity

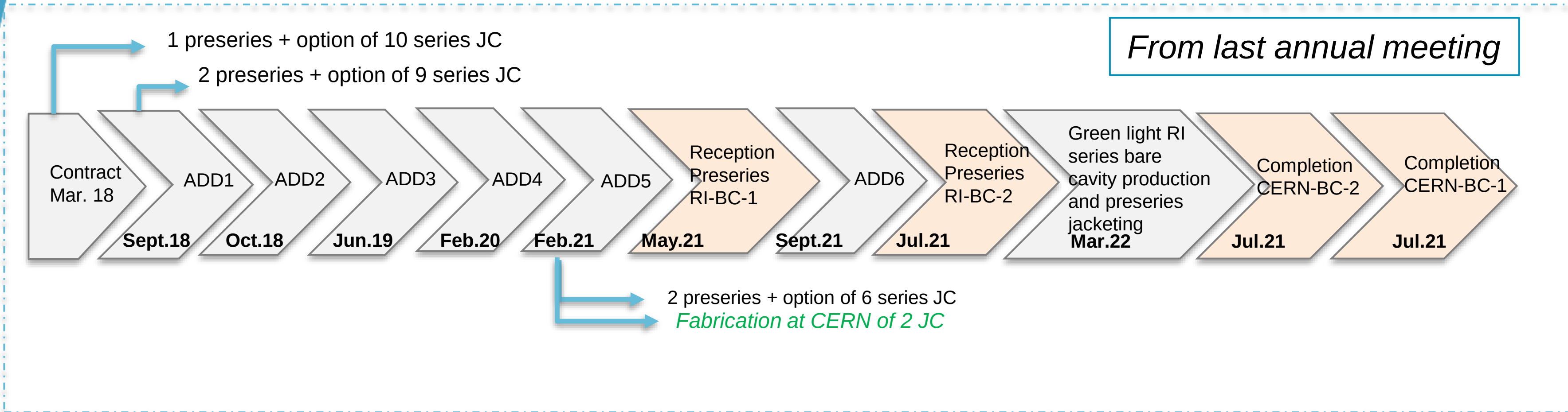
  After qualification of preseries Jacketed cavity by CERN (cold RF test):
    - 10 series Jacketed cavities

DQW Bare cavity

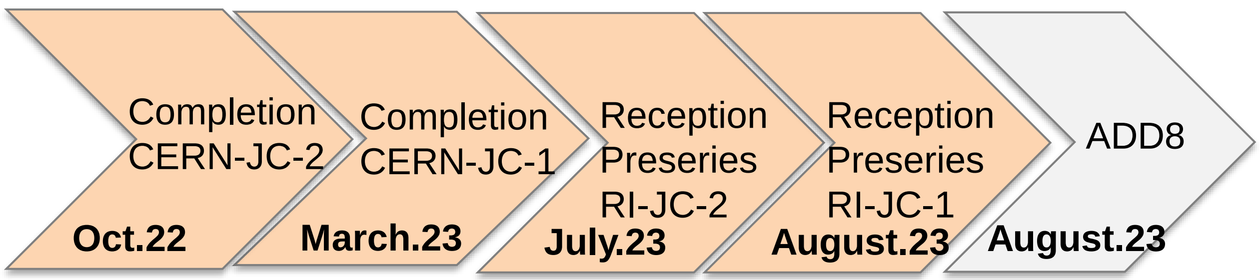


DQW Jacketed cavity

RI Contract Timeline



Main milestones since the last annual meeting:



ADD: Addendum to the contract

Preseries Jacketed cavities RI

05.2021 Reception at CERN Preseries Bare cavity RI-DQW-BC1

07.2021 Reception at CERN Preseries Bare cavity RI-DQW-BC2

03.2022 *Acceptance Preseries bare cavities* — *10 months* →

See talk K.Turaj

RI-BC-1
- **1st cold** test didn't reach specification
- HPR+ clean room assembly at CERN
- **2nd cold test** didn't reach specification
- Light BCP, HPR and clean room assembly at CERN
- **3rd cold test** with successful results : **5.8 MV**

RI-BC-2: 1st cold test reached 5MV

03.2022 *Cavities back to RI for jacketing*

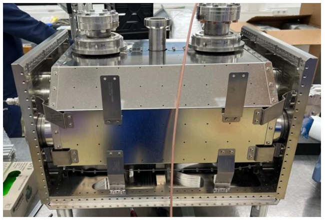
08.2022 *Approval drawings and MIP helium tank*

08-12/2022 *Manufacturing helium tank parts*

08/2022-01/2023 *Procurement special parts (TI Bellows, Ti fasteners)*

08/2022-05/2023 *Welding qualifications* — *9 months* →

- **08-12/2022** Procurement Ti material
- 12/2022-02/2023 Finalisation welding samples
- **02-05/2023** Sample testing by notified body



04.2023 *Assembly helium tank and CMS*

06.2023 *Welding helium tank*

06.2023 *Leak test, pressure test, metrology, RF measurements*

07.2023 *Reception Preseries Jacketed cavity RI-JC-2*

08.2023 *Reception Preseries Jacketed cavity RI-JC-1*

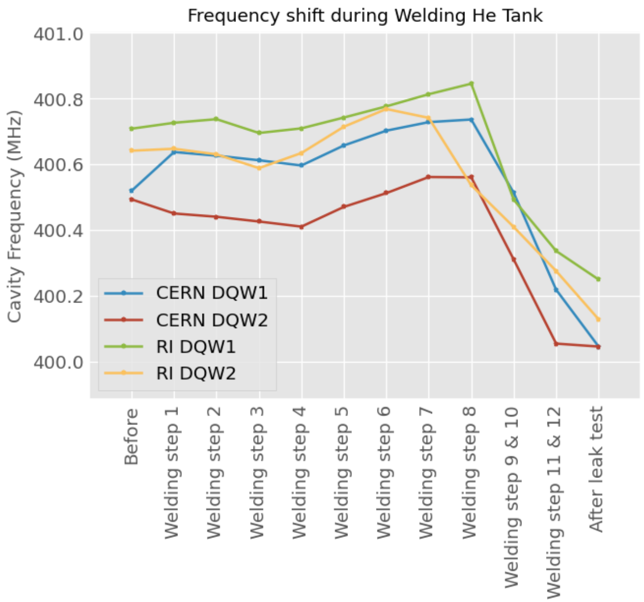
HiLumi HL-LHC PROJECT CERN

Preseries JC RI – Freq. during He tank welding

Fundamental frequency tracking during He tank welding and comparison with CERN cavities

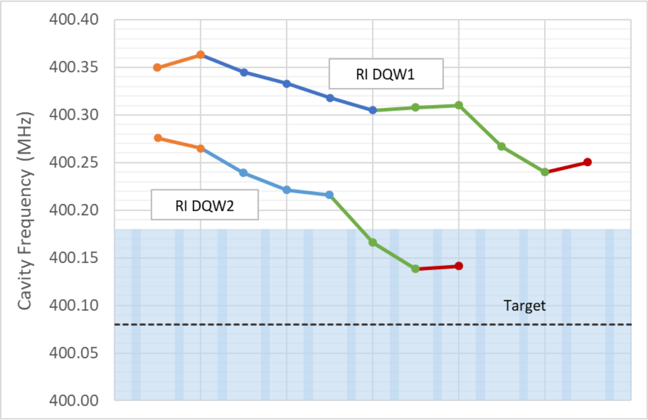
- Jacketing of 4 DQW cavities completed (x2 at CERN, x2 at RI)
- Consistent results
- Frequency drops during the final welds as expected from SPS- DQW experience

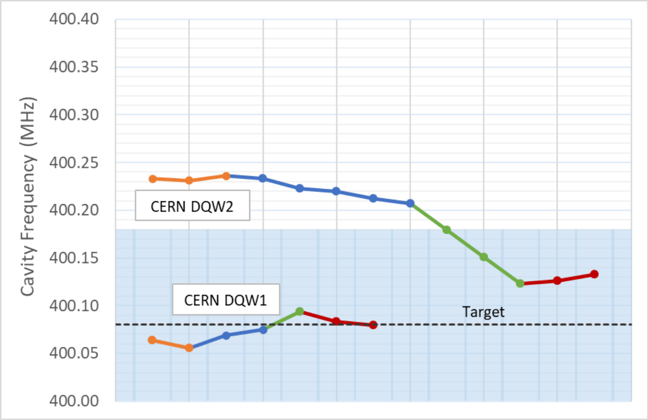
	RI-DQW-JC1	RI-DQW-JC2	CERN-DQW-JC1	CERN-DQW-JC2
Freq. Shift (MHz)	-0.459	-0.454	-0.464	-0.459



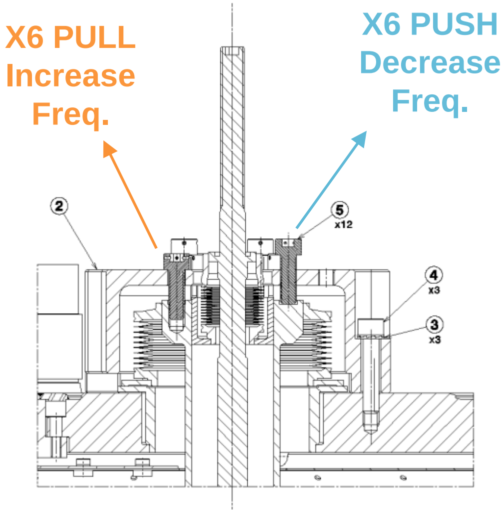
Preseries JC RI – Pre-tuning

The freq. can be modified after welding He tank (pre-tuning).
The cavity can be deformed by applying forces to the pull and push screws and change the RF freq.





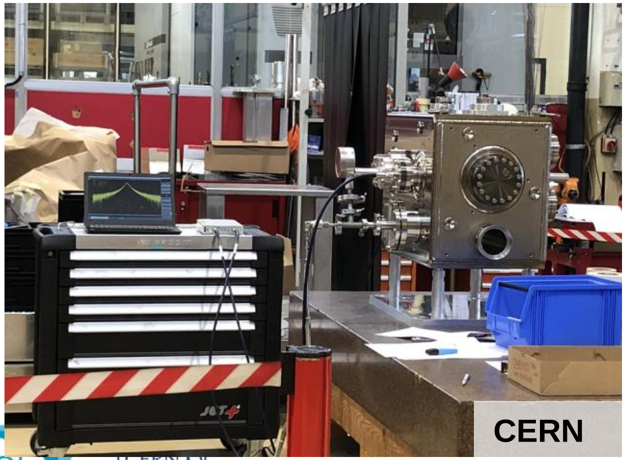
	RI-JC-DQW1	RI-JC-DQW2	CERN-JC-DQW1	CERN-JC-DQW2
Target Frequency (MHz)	400.08 ± 0.1			
Frequency Before (MHz)	400.360	400.276	400.064	400.233
Frequency After Tuning (MHz)	400.250	400.141	400.079	400.133
Tuning Torque Top (Nm)	2.5 Pushing	2.0 Pushing	3.0 Pulling	2.0 Pushing
Tuning Torque Bottom (Nm)	1.5 Pushing	1.5 Pushing	3.0 Pulling	2.0 Pushing



Preseries JC RI – Pressure test

- Differential pressure of 2.7 bar across vessel walls and across cavity walls.
- The required test pressure is maintained for minimum 30 min.
- Fundamental Frequency tracked throughout.

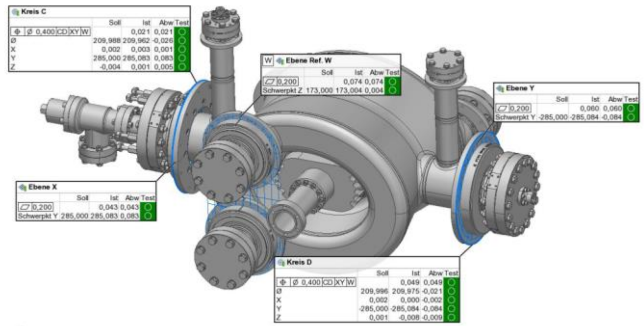
	RI-JC-DQW1	RI-JC-DQW2	CERN-JC-DQW1	CERN-JC-DQW2
Target Frequency (MHz)	400.08 ± 0.1			
Frequency Before (MHz)	400.138	400.248	400.064	400.125
Frequency After Pressure Test (MHz)	400.123	400.277	400.045	400.092
Pressure Sensitivity (Hz/mBar)	-110.85	-104.62	-82.033	-103.85
Maximum Frequency Shift @2.7bar (kHz)	-267	-281	-210	-240
Residual Frequency Shift (kHz)	-15	-21	-19	-33


CERN

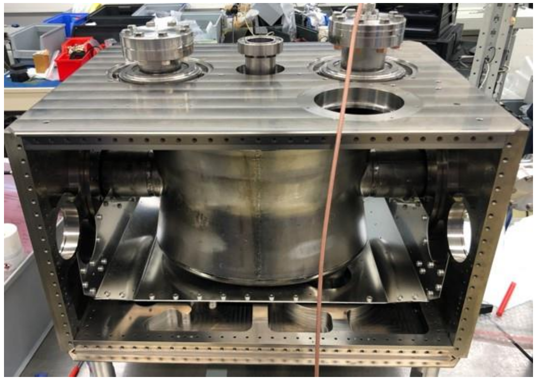

RI

Preseries JC RI

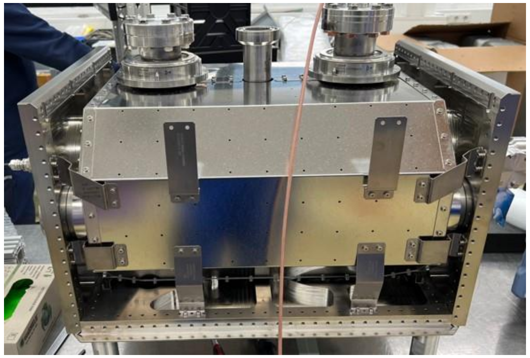
BC with transition rings



Metrology : BC with transition rings



Assembly test with RF measurements



Assembly He tank and CMS

Assembly He tank

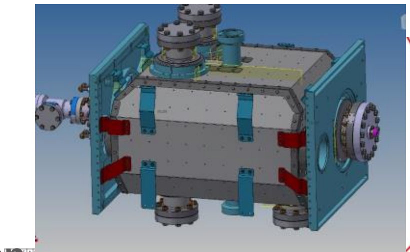
Installation pretuner

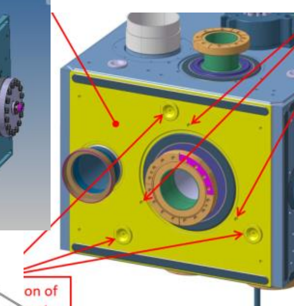
Pressure test with RF follow up

Assembly pretuning system

Preseries JC RI- NCRs

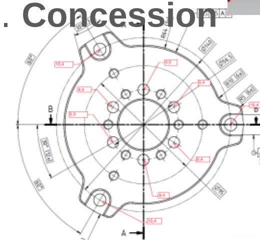
Several NCRs (non-critical), which require deep analysis from several colleagues to understand the implications leading to delays in the planning

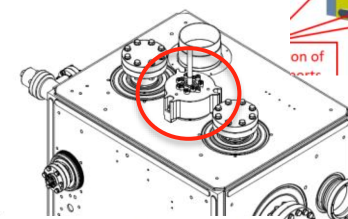




#1 Inverted transversal plates (RI-DQW-JC2): Transversal Helium tank plates were swapped.
Affecting the position of fiducial supports and holes used for tooling.
Concession

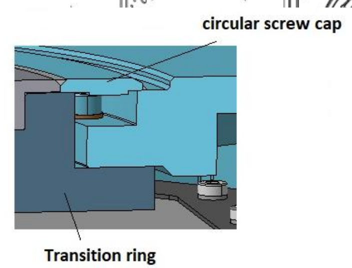
#2 Deviations on the ports, tuner-rod position and beam aperture. **Concession**



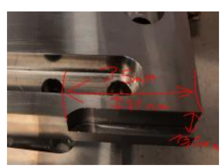


#3 Tuning coarse adjuster : Mounting trouble on both cavities
Repair (enlarging hole diameter)

#4 Beam tube cover plates (RI-DQW-JC2) : Circular screw caps on beam pipes were not in contact with Helium vessel plate making the welding impossible. **Repair**
Lesson learnt: customized circular screw caps will be done for each cavity for all ports to avoid gaps or misalignment.

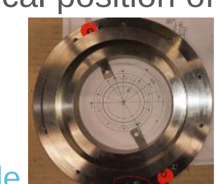


#5 Milling error on Longitudinal plate helium vessel (RI-DQW-JC2). **Concession**



#6 Pick-up plate cavity RI-DQW-JC1: Helium tank plate Pick-up side machined acc. to the theoretical position of the PU ports instead of the real position. **Concession**, the bellow will accommodate the deviation.

#7 Wrong borehole position on beam axis transitions (RI-DQW-JC2) : Milling error- **Repair**



Reception Preseries JC RI

Visual inspection ✓

↓

Freq. meas. warm ✓

↓

Metrology

Clean room assembly at CERN

↓

Cold RF test

See talk K.Turaj

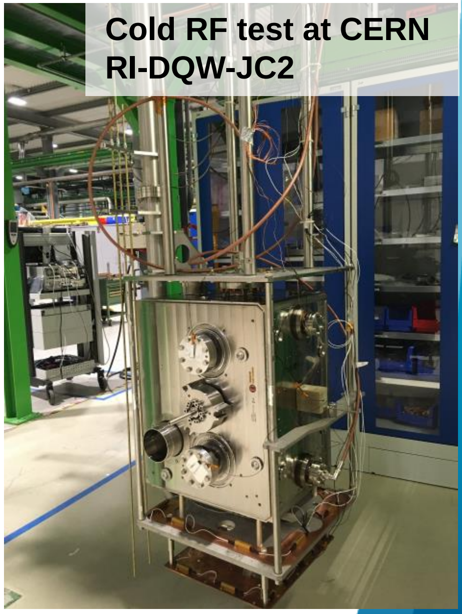
	RI-DQW-JC1	RI-DQW-JC2	Target JC
Freq. (warm, atm. press)	400.23	400.180	400.08 ± 0.1 MHz
Freq. (2K, vacuum)	*Cold RF test in Oct.*	400.93 *	400.79 MHz

* Pre-tuning of JC to reach 400.79 MHz to be done before installation of HOMs

RI-DQW-JC2
- Metrology done. Data being analyzed
- Cold RF test: **Successful results 5.9 MV**

RI-DQW-JC1
- Metrology done. Data being analyzed.
- Cold RF test expected Oct.23

Metrology at CERN of RI-DQW-JC2



Cold RF test at CERN RI-DQW-JC2

Series Bare Cavities RI

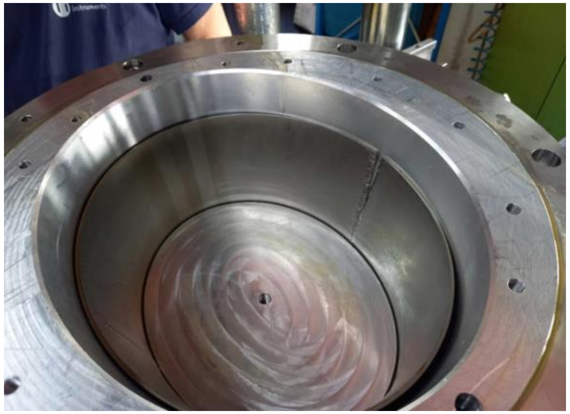
- **03.2022** *Acceptance Preseries bare cavities* → *Green light series bare cavities*
- **05.2023** *Start series bare cavities fabrication*
- **08.2023** *Final Approval drawings and MIP*
- **11.2023** *Delivery to CERN RI-DQW-BC 3*
- **12.2023** *Delivery to CERN RI-DQW-BC 4*
- **02.2024** *Delivery to CERN RI-DQW-BC 5*
- **02.2024** *Delivery to CERN RI-DQW-BC 6*
- **03.2024** *Delivery to CERN RI-DQW-BC 7*
- **03.2024** *Delivery to CERN RI-DQW-BC 8*

Series BC RI- NCRs

Several NCRs which require deep analysis from several colleagues to understand the implications. Some NCR can´t be assessed until cavity cold RF test is done.

#1 Wrong position M5 holes on NbTi flange: Milling error- Accepted- Modification of adaptative rings accordingly.

#2 Low thickness after necking out for pick-up port : Concession



#3 Brazing pick-up port, lack of filler metal on the front side. Scrap

#9 Crack on the longitudinal weld of main body during forming : Scrap

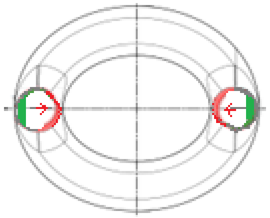
#4 Error on the Brazing cycle: Scrap (x27 pieces)

#5 Low thickness necking elliptical cap: Concession

#6 Brazing- wrong alignment during assembly- Scrap

#7 Depth of pockets for welding beans and pin on bowl was smaller than requested – Milling error- Concession

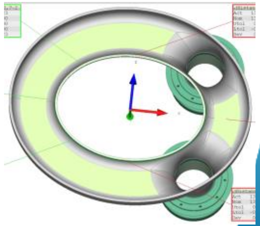
#8 Necking out of elliptical done with wrong tooling- Scrap



#10 Deviations on bowls- Concession

#13 Deviation position HOM and FPC ports

#11 Milling of beam tubes for necking out done in the wrong direction: Scrap



#12 Pin out of tolerances (x1). Scrap

#14 Deviation distance between RF surface elliptical cap to the bowl weld joint- under review

Documentary structure RI

Documentary structure of the contract (EDMS) in place and actively used by the supplier. Full traceability of documents and versions.

Many interactions with the supplier to achieve the quality level requested by the technical specification (EDMS 1803555).

- DQW Jacketed Cavities Industrial Production
  - Documents shared by CERN
  - Documents provided by the Contractor
    - Contract Management
    - Bare Cavities [ACFCA]
      - Detailed Design File
        - Drawings
        - 3D Models
      - Documentation prior to manufacturing the BC
        - Welding Procedure Qualification Record - WPQR
        - Welding Procedure Specification - WPS
        - NDTs Personnel Qualification
        - Welding Operator Performance Qualifications - WOPQ
        - 1887278 (v.8) Welding map
        - 1887280 (v.3) Brazing procedure qualification record (BPQR)
        - 1887282 (v.1) Brazing procedure specification (BPS)
        - 1887283 (v.1) Welding operator performance qualification (WOPQ)
        - 1887284 (v.2) Brazing operator performance qualification (BOPQ)
        - 1887285 (v.1) Non-destructive Test personnel qualification
      - E-B welding and brazing Samples
      - MIP and Procedures
        - 1887287 (v.7) Manufacturing and Inspection Plan Pre-series
        - 2712912 (v.3) Manufacturing and inspection plan - Series
        - 1887289 (v.6) BCP Procedure
        - 2050479 (v.6) Chemical Surface Treatment of Niobium and Nb55Ti
        - 1887290 (v.3) HPWR procedure
        - 1887291 (v.4) Heat Treatment Procedure
        - 2041072 (v.6) Brazing procedure
        - 2050505 (v.3) Helium leak test procedure
        - 2067217 (v.3) Ultrasonic Testing Procedure
        - 2082966 (v.4) Cleaning procedure for SS, Cu and Ti
        - 2113095 (v.3) Grinding of Niobium procedure
        - 2257799 (v.4) RF measurement and trimming procedure
        - 2268021 (v.4) Manufacturing and Inspection Plan Pre-series-Treatment Processing
        - 2375144 (v.2) Venting procedure
        - 2375168 (v.1) Report Templates related to surface treatment
        - 2393441 (v.1) Report templates related to bare cavity fabrication
      - Materials Traceability
      - Manufacturing Records
      - HCACFCA001 (v.0) DQW Bare Cavity (Variant #1)
    - Jacketed Cavities [ACFDC]
      - Detailed Design File
      - Documentation prior to manufacturing the JC
        - Welding Procedure Qualification Record - WPQR
        - Welding Procedure Specification - WPS
        - 1887296 (v.2) Welding map
        - 1887297 (v.1) Welding procedures qualification record (WPQR)
        - 1887298 (v.1) Welding procedure specification (WPS)
        - 1887299 (v.1) Welding operator performance qualification (WOPQ)
        - 1887300 (v.1) Non-destructive Test personnel qualification
        - 1887301 (v.1) Welding Consumables Certificates
        - 1887302 (v.1) Materials Certificates of the JC
      - MIP and Procedures
        - 1887303 (v.3) Manufacturing and Inspection Plan Pre-series
        - 1887304 (v.1) Manufacturing procedures
        - 1887305 (v.1) Cleaning procedures
        - 1887306 (v.1) Manufacturing and Inspection Plan Series
        - 2038120 (v.6) Pressure test procedure
      - Materials Traceability
      - Documentation of Bellows
      - Manufacturing Records

Equipment Identifier: **HCACFHT003-RN000002**
Other Identifier: None
Description: **DQW Jacketed Cavity Pre-Series**

Main | Made of | Equipment data | **Manufacturing** | Operation | Non-conformities | Documents | History | Map

Actions : Add extra step

Workflow Diagram

No workflow diagram is defined for this equipment

Workflow Steps — Last Repeated

Step	R/E	Other name	Description	Status	Result	NC
5		()	Traceability of Materials (*)	Pending		
10		()	Related MIP (*)	Done	Ok	
15		()	P111034 - 2.1.3 Dimensional control (*)	Done	Ok	
20		()	P111034 - 2.1.5 Dimensional control if needed (*)	Cancelled		
25		()	P111035 - 2.2.3 Dimensional control (*)	Done	Ok	
30		()	P111035 - 2.2.5 Dimensional control if needed (*)	Cancelled		
35		()	P111050 - 2.3.3 Dimensional control (*)	Done	Ok	
40		()	P111050 - 2.3.5 Dimensional control if needed (*)	Cancelled		
45		()	P111051 - 2.4.3 Dimensional control (*)	Done	Ok	
50		()	P111051 - 2.4.5 Dimensional control if needed (*)	Cancelled		
55		()	P111052 - 2.5.3 Dimensional control (*)	Done	Ok	
60		()	P111052 - 2.5.5 Dimensional control if needed (*)	Cancelled		
65		()	P111053 - 2.6.3 Dimensional control (*)	Done	Ok	
70		()	P111053 - 2.6.5 Dimensional control if needed (*)	Cancelled		
75		()	P111054 - 2.7.3 Dimensional control (*)	In Progress		
80		()	P111055 - 2.8.3 Dimensional control (*)	Done	Ok	
85		()	P111056 - 2.9.3 Dimensional control (*)	Done	Ok	
90		()	P111057 - 2.10.3 Dimensional control (*)	Done	Ok	
95		()	P111077 - 2.16.3 Dimensional control (*)	Done	Ok	
100		()	P111105 - 2.17.3 Dimensional control (*)	Pending		
105		()	P111103 - 2.18.3 Dimensional control (*)	Done	Ok	
110		()	P111109 - 2.22.3 Dimensional control (*)	Done	Ok	
115		()	P111969 - 2.26.3 Dimensional control (*)	Done	Ok	
120		()	P111973 - 2.27.3 Dimensional control (*)	Done	Ok	
125		()	P111975 - 2.30.3 Dimensional control (*)	Done	Ok	
130		()	P111974 - 2.30.3 Dimensional control (*)	Done	Ok	
135		()	P112005 - 2.46.3 Dimensional control (*)	Pending		
140		()	P112008 - 2.48.3 Dimensional control (*)	Done	Ok	
145		()	P112009 - 2.49.3 Dimensional control (*)	Pending		
150		()	P141065 - 2.50.3 Dimensional control (*)	In Progress		
155		()	P111106 - 3.1.1 VT before welding (*)	Pending		
160		()	P111106 - 3.1.3 VT after welding (*)	Pending		
165		()	P111112 - 3.3.1 VT before welding (*)	Pending		
170		()	P111112 - 3.3.3 VT after welding (*)	Pending		
175		()	P111972 - 3.5.1 VT before welding (*)	Pending		
180		()	P111972 - 3.5.3 VT after welding (*)	Pending		
185		()	P112007 - 3.8.1 VT before welding (*)	Pending		
190		()	P112007 - 3.8.3 VT after welding (*)	Pending		
195		()	P111036 - 4.1.3 Y-F01 RF Frequency control (*)	Done	Ok	
200		()	P111036 - 4.1.5 HOLD POINT-Check Tuner (*)	Done	Ok	
205		()	P111036 - 4.1.6 Y-F02 RF Frequency control (*)	Done	Ok	
210		()	P111072 - 4.2.2 Y-F03 RF Frequency control (*)	Cancelled	Cancelled	
215		()	P111113 - 4.3.5 Y-F04 RF Frequency control (*)	Done	Ok	
220		()	P111113 - 4.3.11 Y-F05 RF Frequency control (*)	Done	Ok	
225		()	P111113 - 4.3.18 Y-F06 RF Frequency control (*)	Done	Ok	
230		()	P111113 - 4.3.20 Y-F07 RF Frequency control (*)	Done	Ok	
233	E	()	P111113 - 4.3.22 Y-F08 RF Frequency Control	Done	Ok	
235		()	P112001 - 4.4.2 Y-TIG-01 VT before welding (*)	Pending		
240		()	P112001 - 4.4.4 Y-F09 RF frequency control (*)	Done	Ok	
245		()	P112001 - 4.4.6 Y-F10 RF frequency control (*)	Done	Ok	
250		()	P112001 - 4.4.8 Y-F11 RF frequency control (*)	Done	Ok	
255		()	P112001 - 4.4.10 Y-F12 RF frequency control (*)	Done	Ok	
260		()	P112001 - 4.4.12 Y-F13 RF frequency control (*)	Done	Ok	
265		()	P112001 - 4.4.14 Y-F14 RF frequency control (*)	Done	Ok	
270		()	P112001 - 4.4.16 Y-F15 RF frequency control (*)	Done	Ok	
275		()	P112001 - 4.4.18 Y-F16 RF frequency control (*)	Done	Ok	
280		()	P112001 - 4.4.20 Y-F17 RF frequency control (*)	Done	Ok	
285		()	P112001 - 4.4.22 Y-F18 RF frequency control (*)	Done	Ok	
290		()	P112001 - 4.4.26 Y-TIG-02 VT after welding (*)	Pending		
295		()	P112010 - 4.5.5 Y-TIG-03 VT after welding (*)	Pending		
300		()	P112010 - 4.5.6 Y-F19 RF Frequency control (*)	Done	Ok	
305		()	P112010 - 4.5.11 Y-TIG-04 VT after welding (*)	Pending		
310		()	P112010 - 4.5.12 Y-F20 RF Frequency control (*)	Done	Ok	
312	E	()	P112010 - 4.5.13 Installatio pretuning system	Pending		
315		()	P112010 - 4.5.14 Y-F21 RF Frequency control (*)	Done	Ok	
320		()	P112010 - 4.5.15 Dimensional Control (*)	In Progress		
325		()	P112010 - 4.5.16 He leak test of helium tank and 2nd beam pipe (*)	Done	Ok	
330		()	P112010 - 4.5.17 He leak test of Bare cavity (*)	Done	Ok	
335		()	P112010 - 4.5.18 Y-F22 RF Frequency control (*)	Done	Ok	
340		()	P112010 - 4.5.19 Pressure test (*)	In Progress		
345		()	P112010 - 4.5.20 Y-F23 RF Frequency control (*)	Done	Ok	

Cavity and CM testing in SM18

See talk K.Turaj

Number of cavity cold tests increased from 2022 to 2023.
New insert in preparation to ease the planning
Dressed cavities are more challenging and require more clean room resources.
Bottlenecks for 2024: clean room resources with cavity preparation and string assembly.
helium availability in SM18

2022
6 Cold RF test CC:
- 4 Bare cavities *3 successful*
- 2 Jacketed cavities *1 successful*

2023
10 Cold RF test CC:
- 3 Jacketed cavities *3 successful*
- 7 Dressed cavities *1 successful, 3 not suc*

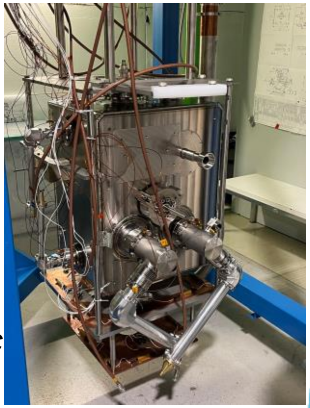
1 CM cold test

2024
10 Cold RF test CC:
- 6 Bare cavities
- 3 Jacketed cavities
- 1 Dressed cavity

1 CM string assembly
1 CM cold test

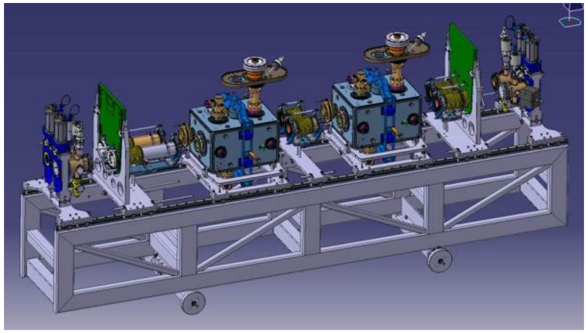
2025
8 Cold RF test CC:
- 3 Jacketed cavities
- 5 Dressed cavities

2 CM cold test

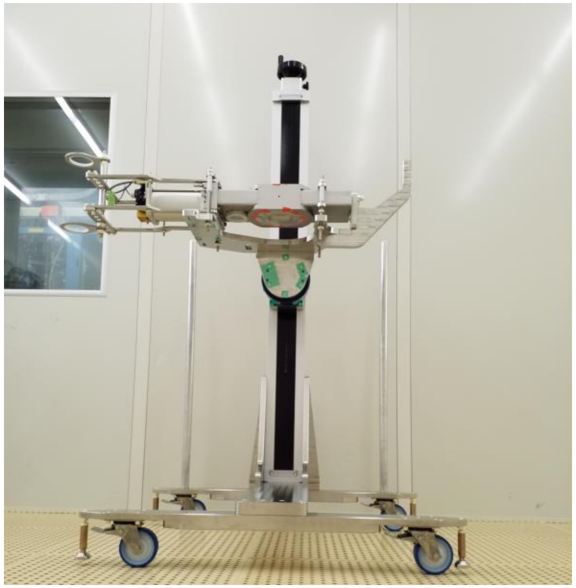


CERN Cleanroom tooling for cavities string assembly

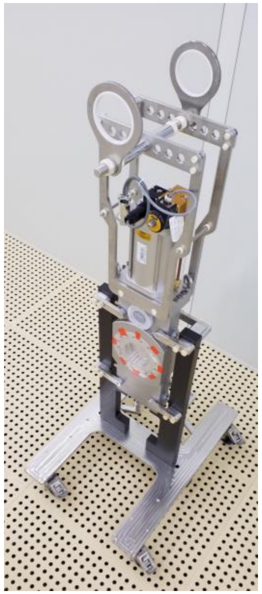
- **Goal :** design & produce tools to interconnect & align easily the full cavities string, aiming at keeping the cavity line ISO 4 (ISO 14644 cleanroom norm)
- **Result :** complete tooling set for cavities string handling, and extremity vacuum chambers subassembly, anti-dust prepared in less than 4 weeks



Interconnection & alignment tooling for complete string



Rotating system:
Cleaner assembly of the Extremity Vacuum Chambers with the various valves and gauges



Sector valve handling frame and cleanroom intermediate storage trolley

Process development for Plug In Modules subassembly

Goal : would it be possible to assemble PIMs outside cleanroom and perform anti-dust conditioning afterward, in order to save resources and improve cleanliness ?

RFD 2021 summary :

*Parts degreased and manually cleaned outside cleanroom ; rinsed ; then assembled inside cleanroom

Status after rinsing, before assembly :

Inside RF fingers and inside bellow convolutions : ISO 2-3

Outside bellow's surface and flanges : ISO 6

Status after assembly in cleanroom :

Inside RF fingers and inside bellow convolutions : ISO 6

Fixing area with Ag coated screws & springs : ISO 5, it was ISO 8 before a huge effort of wiping and blowing inside cleanroom

⇒ **Maintaining sub-ISO 4** is **not possible** due to **complex assembly sequence** and need of **tightening coated fasteners** inside the assembly (between the bellow and the RF finger)

Should not have been accepted for string assembly, but we could not do better with this procedure

DQW 2023 summary :

*Parts degreased, manually cleaned and assembled outside cleanroom ; whole subassembly rinsed inside cleanroom

After rinsing of the whole subassembly :

Outside surface : ISO 4

Inside surface : ISO 4

Fixing area with springs : ISO 5 without extra wiping nor blowing

Accepted for string assembly

NB: Requested a strong care in order to dry the subassembly correctly

A factor 3 in time saving !

A factor 100 in cleanliness level improvement !

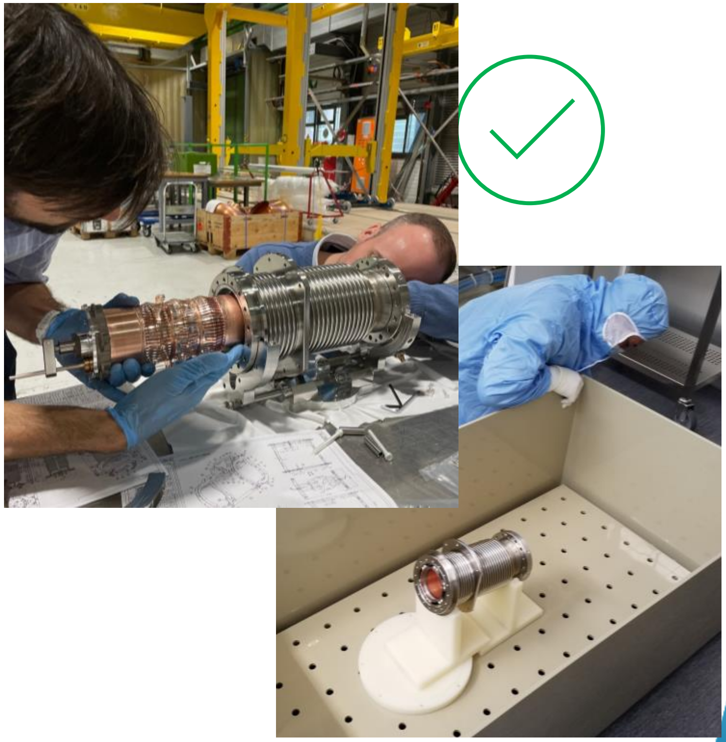
Versus

Process development for Plug In Modules subassembly

Result :

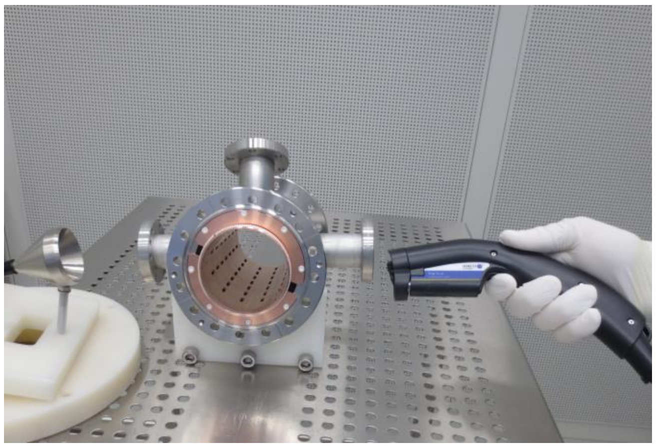
- It has been proven it is possible to dry the subassembly after rinsing.

  It requires a lot of care, but it is feasible without baking out.
- The inside of the subassembly went from **ISO 6 for RFD**, to **ISO 4 for DQW**.

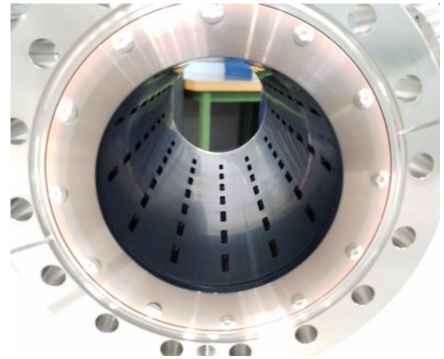


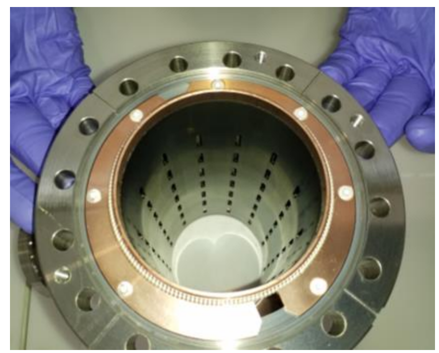
Cleanliness study of Extremity Vacuum Chamber

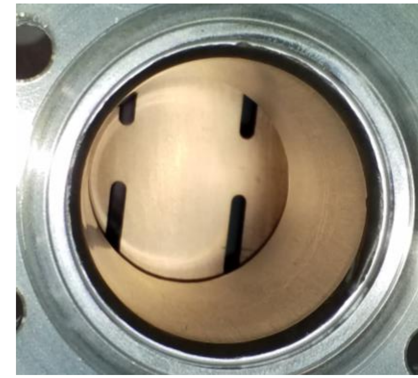
<u>Goal :</u> cleanroom conditioning comparison of DQW Extremity Vacuum Chamber Before vs. After carbon thin film coating



aC coating →







No coating inside the DN40 pipes, no significant backward coating of the grid through the holes (<u>only observed by eye</u>)

	EVC 5 BC	EVC 5 AC	EVC 6 BC	EVC 6 AC
Outside :	ISO 5	ISO 6	ISO 5	ISO 6
Inside :	ISO 3	ISO 5	ISO 4	ISO 4
Cu RF fingers area :	ISO 3	ISO 4	ISO 3	ISO 4

Before coating = BC // After coating = AC

Cleanliness study for Extremity Vacuum Chamber

Result :

-Chemical etching of the chambers removed all the oxides and brought the inside cleanliness level from ISO 5 to ISO 4.

-The outer surface gets dirtier each time we prepare these subassemblies. It is necessary to assess where the pollution comes from, and how can we keep the outer surface in the ISO 5 range at maximum.

-Even if the two EVCs are rejected for string assembly in the actual state, the rinsing test showed very promising results :

*Observation is similar to the PIM experience and it is validated it is possible to assemble the grids inside the chambers outside cleanroom, operate cleanroom conditioning, and dry the subassemblies successfully.

*It showed the Cu grid did not oxidized during the cleanroom conditioning in air.

*The coating is closer to be accepted than expected (reminder: the coated Beam Screens for secondary line were ISO 7), but this study is missing an understanding of the reproducibility, since only two EVCs were tested and showed different outcomes.

Decisions are being discussed regarding the coating process and goal in regard with the context of length and position of these subassemblies.

Conclusions

- RI preseries jacketed cavities delivered to CERN. First cavity reached 5.9MV at 2K and second cavity will be tested soon. Metrology data under review.
- Expected delivery for RI **series** bare cavities (x6): from Q4 2023 to Q1 2024.
- Several NCRs leading to planning delays. Planning evolving.
- Frequency measurements during cavity fabrication (welding, trimming, pressure test, pre-tuning) consistent with results at CERN.
- Cavity testing in SM18 is ramping up. Bottle neck for 2024: clean room resources to cope with cavity preparation and string assembly.
- Tooling for string assembly of CERN DQW CM is ready.
- Cleanliness studies for PIMs proved it is possible to assembly PIMs outside cleanroom and perform anti-dust conditioning afterward.

Thank you!