RF Performance Results of RF DQW cavities for LHC HL-LHC Project

Katarzyna Turaj on behalf of WP4 and SY-RF-SRF

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Outline

- Introduction
- Simplified process flow of DQW cavities
- Frequency evolution and Tuning
- Surface preparation and Clean Room Assembly
- Cold test set-up
- Cold tests results of DQW cavities
  - 2 series DQW-RI
  - 2 series DQW-CERN
- Conclusions

HL-LHC Cavity Geometries

Double Quarter Wave (DQW) cavity
– to be used in Point 5 (CMS), vertical

$$f_0 = 400.79\ \text{MHz}$$

$$V_T = 3.4\ \text{MV/cavity}^*$$

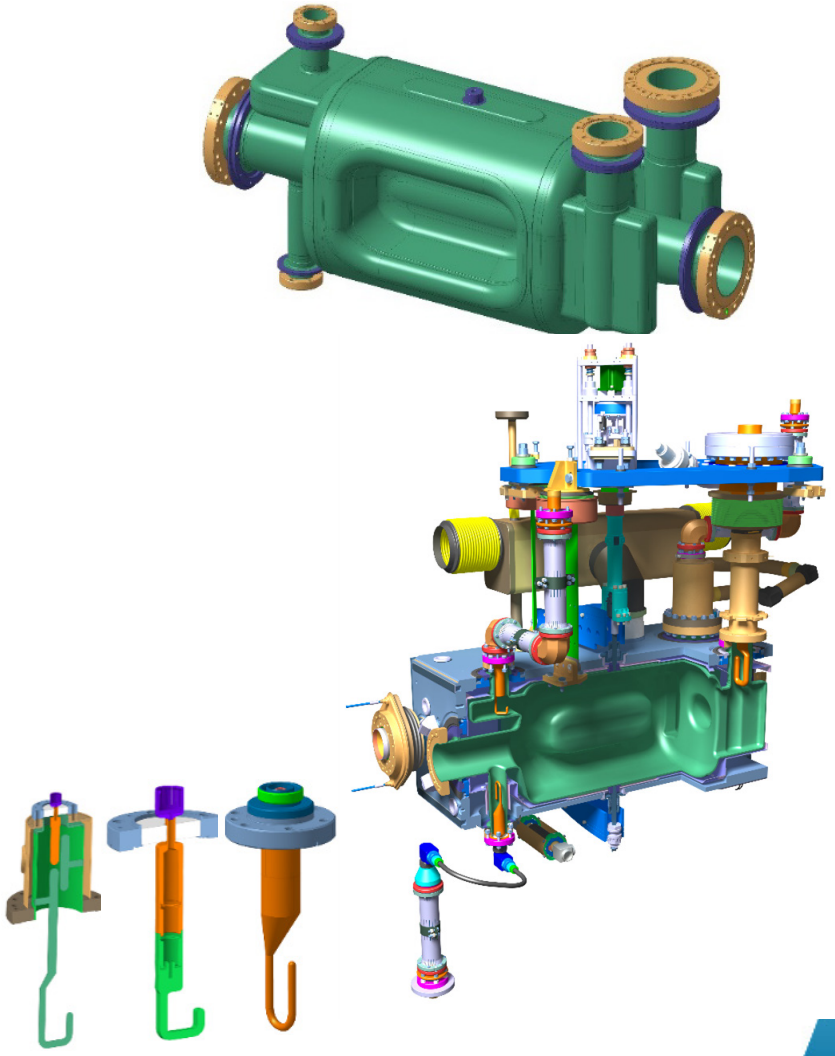
$$(E_p, B_p < 40\ \text{MV/m}, 70\ \text{mT})$$

$$\text{Beam aperture} = 84\ \text{mm}$$

$$\text{RF power} = 40\ \text{kW-CW}$$

$$\text{Operating Temp} = 2\ \text{K}$$

Radio Frequency Dipole (RFD) cavity
– to be used in Point 1 (ATLAS), horizontal



*Engineering spec: 4.1 MV dressed for 20% margin

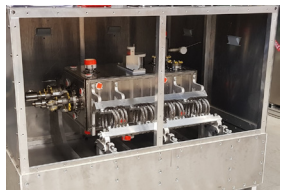
Timeline, HL –LHC Crab Cavities

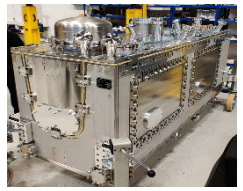
High Power RF system not shown below

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027

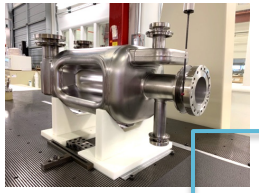
DQW CM SPS-tests

RFD CM SPS-tests

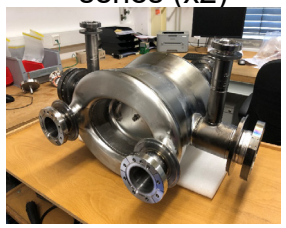




USAUP-RFD proto (x2)

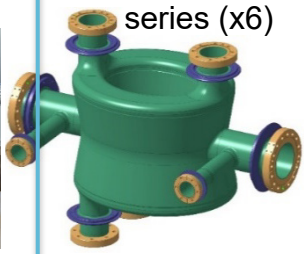


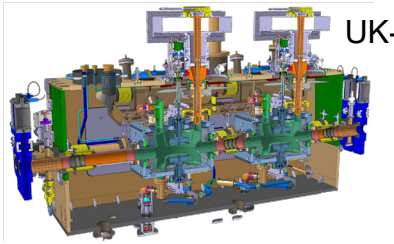
RI-DQW series (x2)



CERN-DQW series (x2)

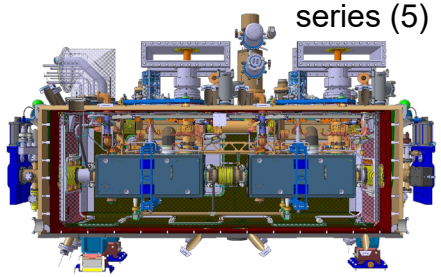
RI-DQW series (x6)



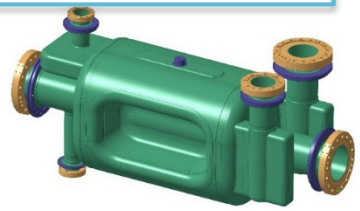


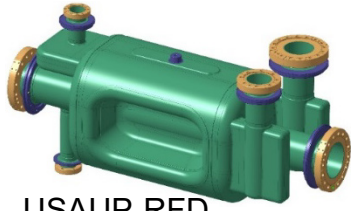
UK-CERN DQW CMs series (4 + 1)

Canada-CERN RFD CMs series (5)



USAUP-RFD pre-series (2)





USAUP-RFD series (10)

DQW cavities

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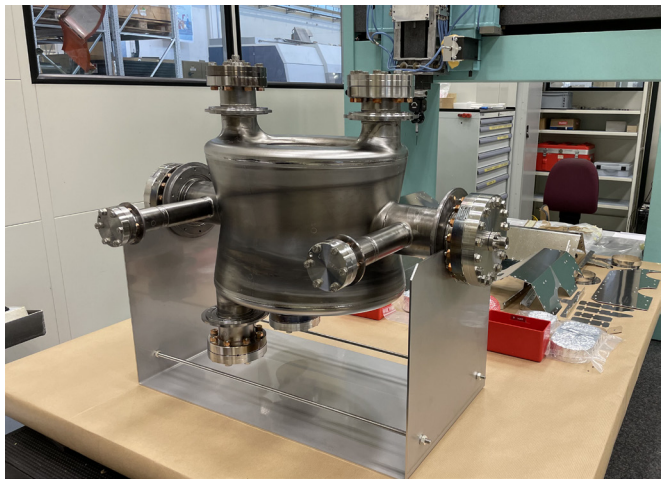

DQW cavities

- Crab cavities are tested at 2K in 3 different configurations
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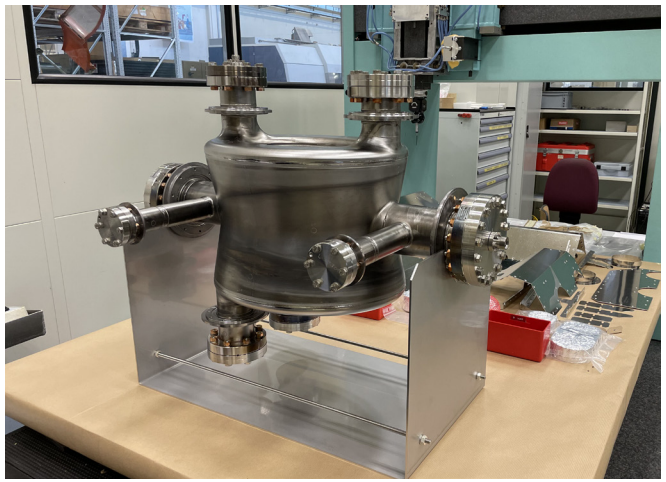
  - Jacketed cavity (JC) → BC + Cold Magnetic Shield + He Tank



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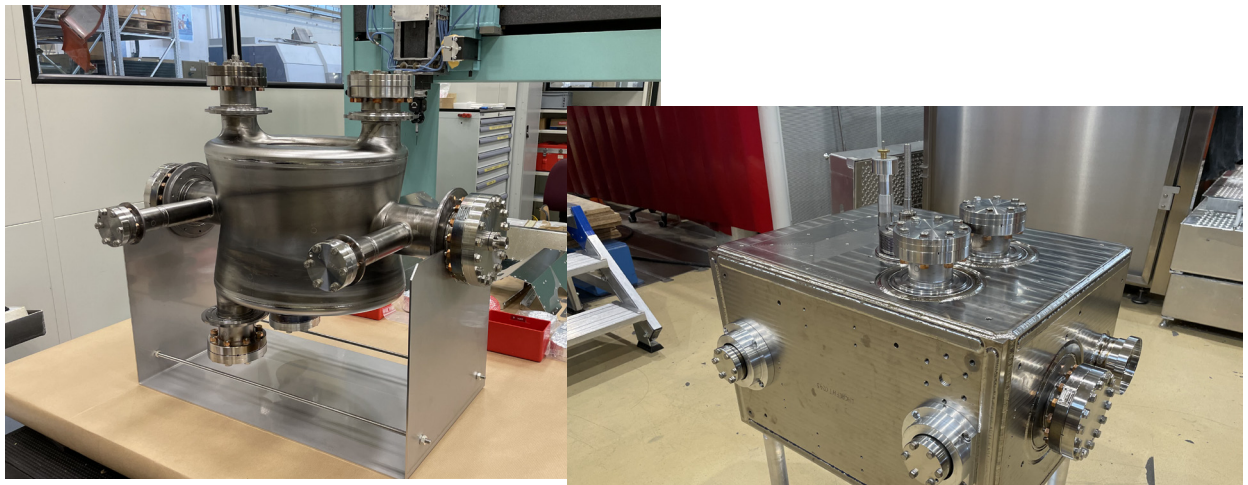

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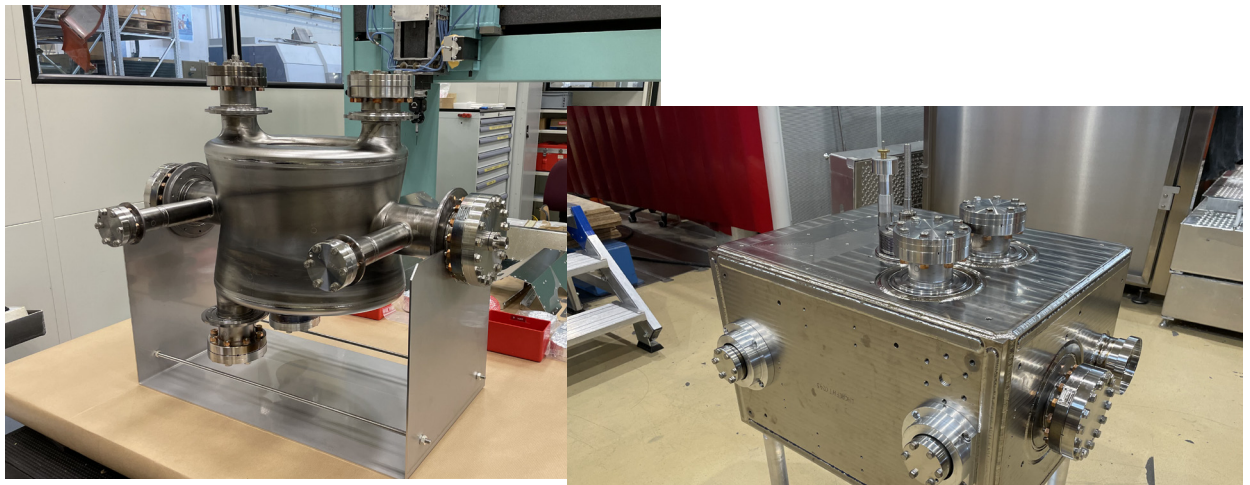
  - Dressed cavity (DC) → JC + RF couplers (3 HOMs, 1 HF HOM, 1 FA)



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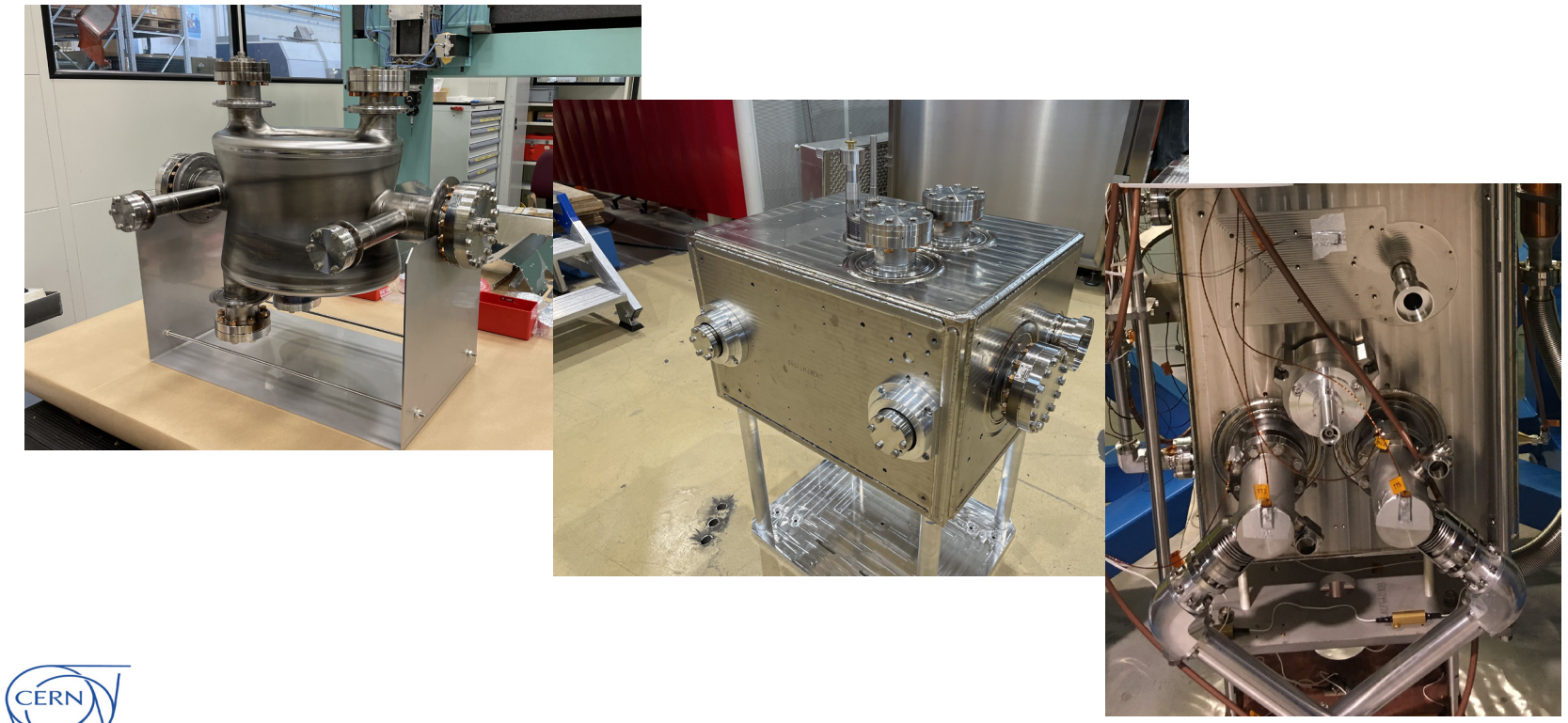
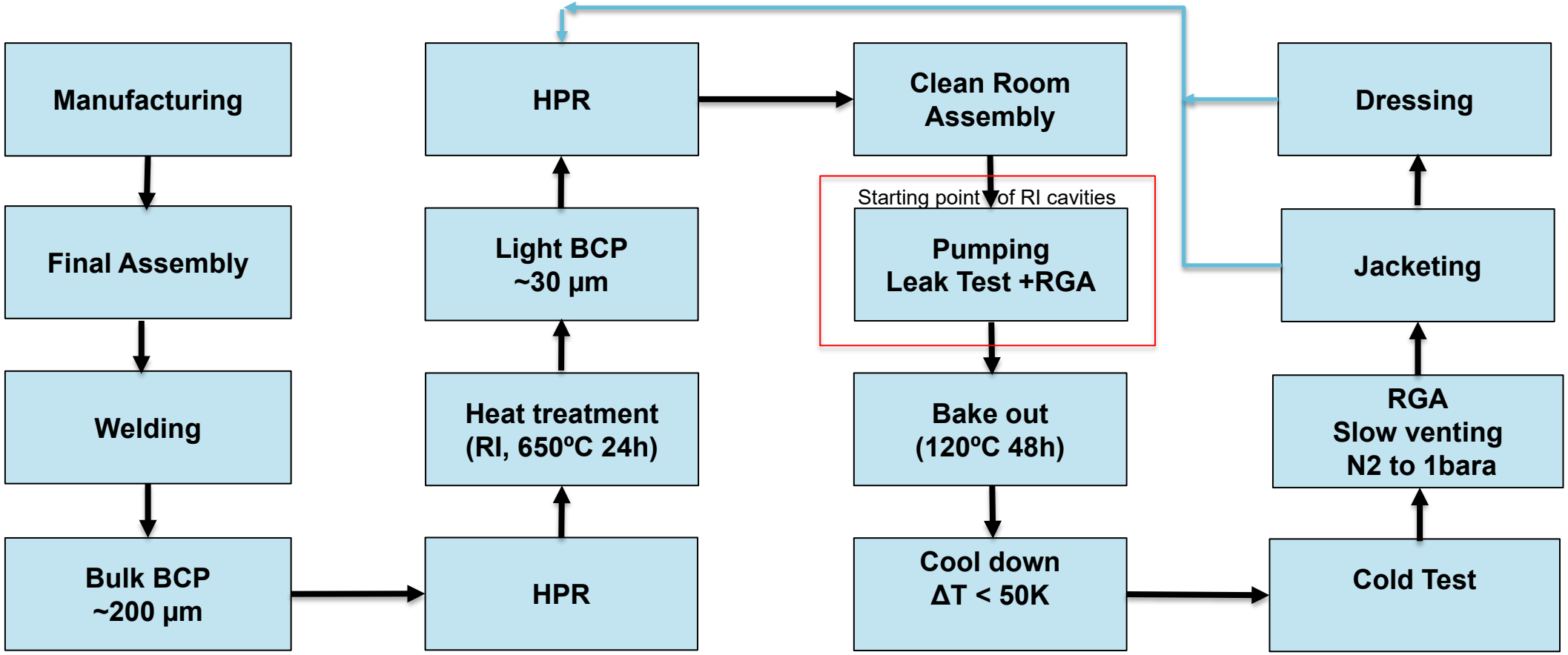


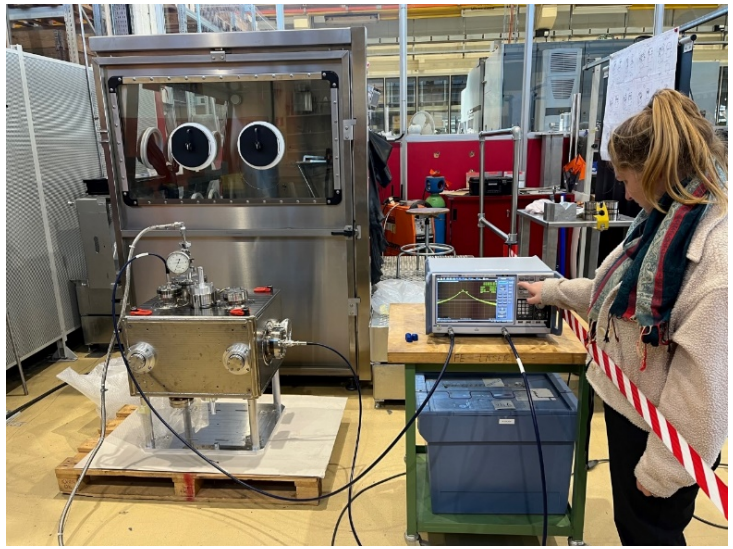
Simplified process flow of DQW cavities

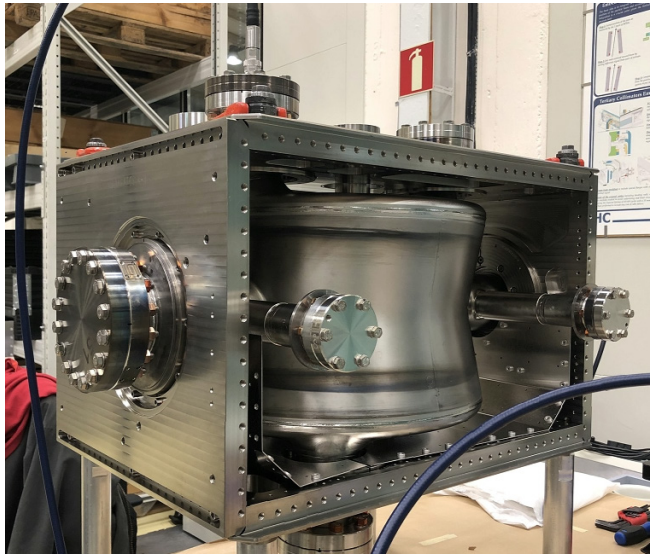
- Similar preparation and testing process.
- Inspection and frequency measurement between each step

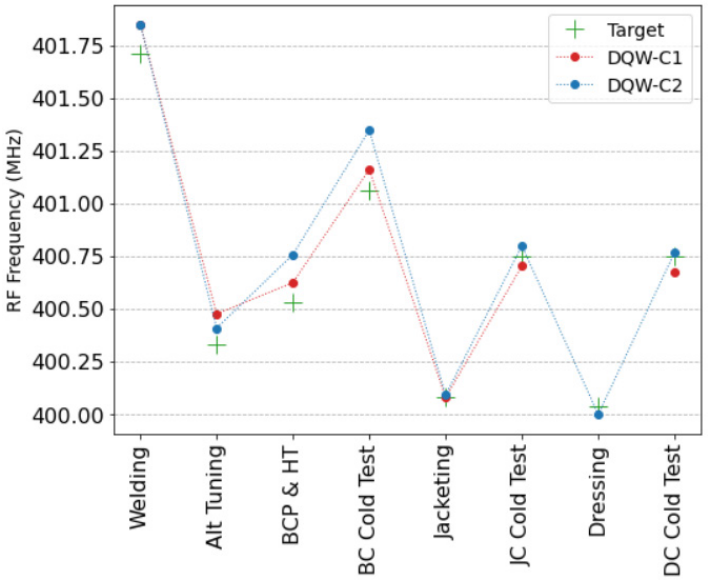


Frequency Evolution and Tuning

- Many operations during fabrication, preparation and operation lead to frequency shifts and uncertainties.
- Several tuning steps are envisaged at different stages
- HOMs also tracked throughout manufacture



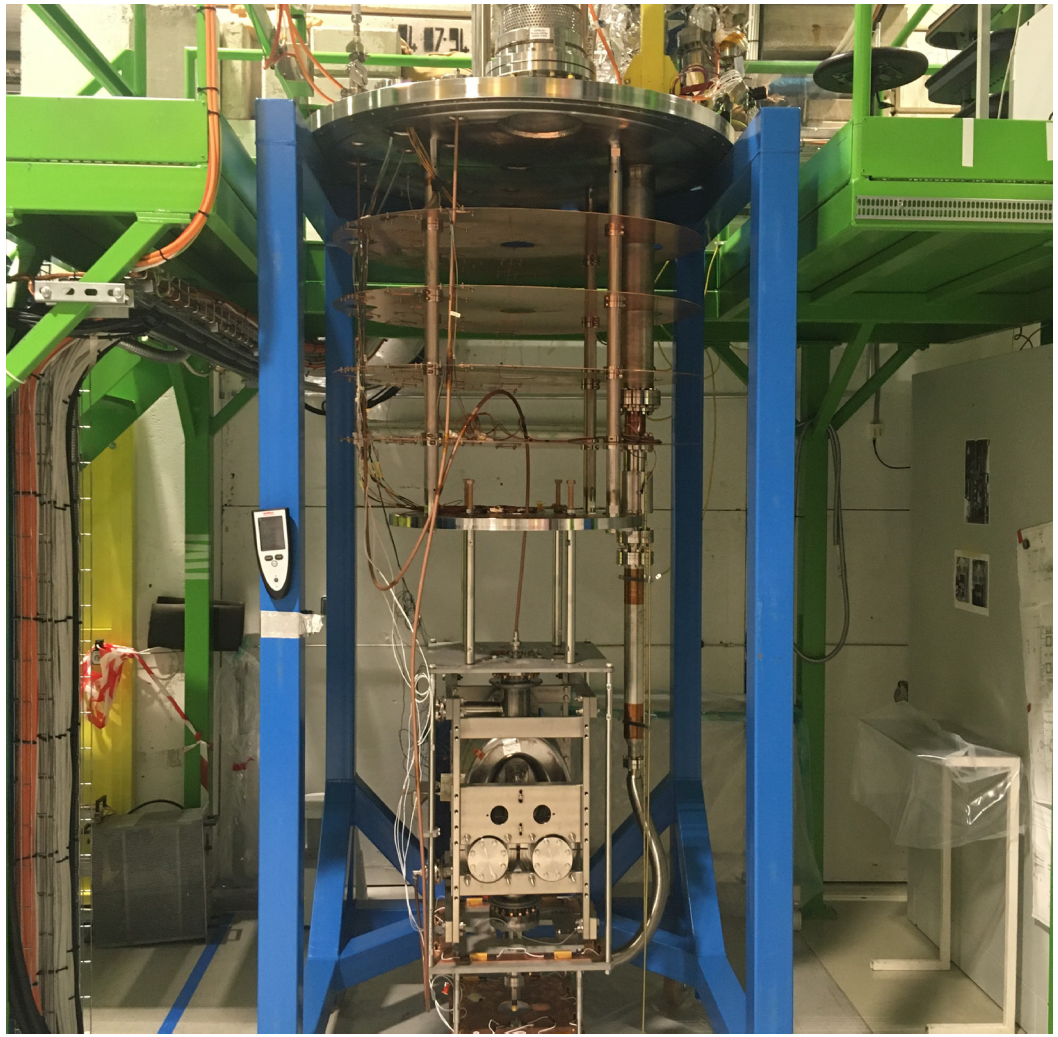




Frequency evolution of DQW cavities produced by CERN for the fundamental mode.

Cold test set-up

- Test temperature: 2K
- Sensors used during the tests:
  - Temperature sensors: CERNOX
  - 3 single-axis magnetic flux probes
  - Radiation monitors (different position depends on the cryostat)
- Cryostats are equipped with magnetic field compensation coils - set at ~0.5μT (BC)
- Stiffening frame for bare cavities
- JC and DC tested fully immersed in the LHe bath
- Cavity vacuum actively pumped by turbo and ion pump, then only cryopumping



DQW series cavity built by Industry (RI): DQW1 & DQW2

Bare Cavity Test Results – DQW1-RI-BC

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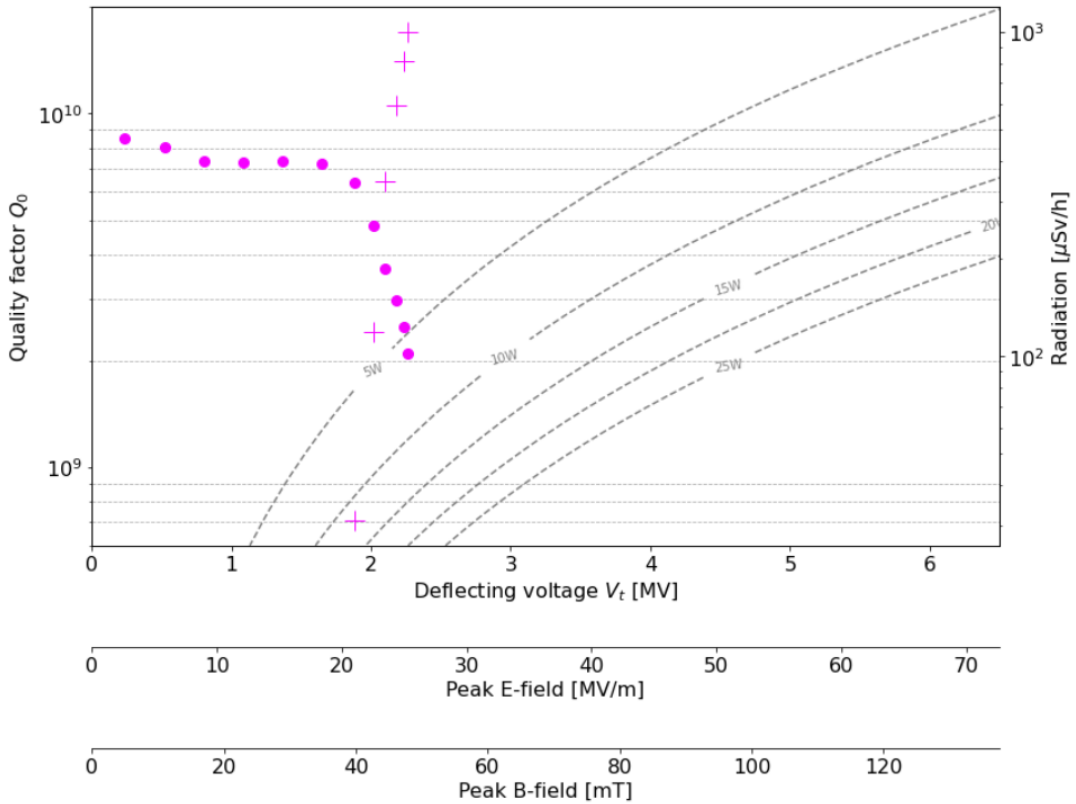

Bare Cavity Test Results – DQW1-RI-BC

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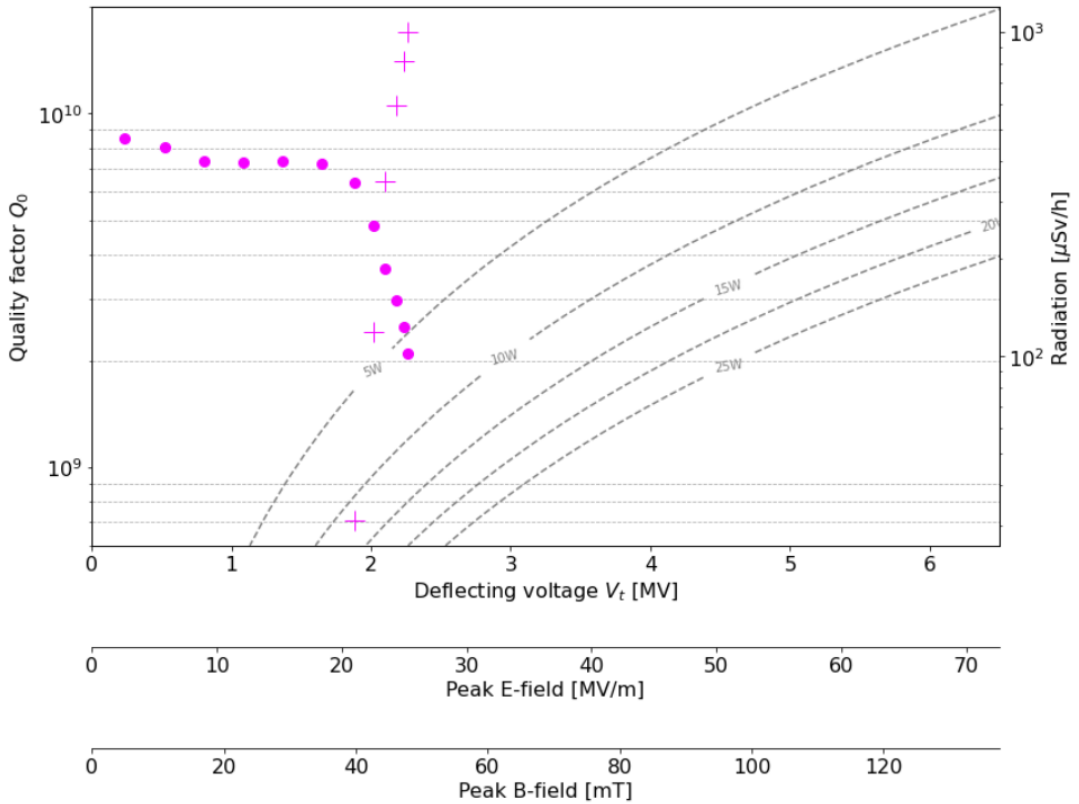

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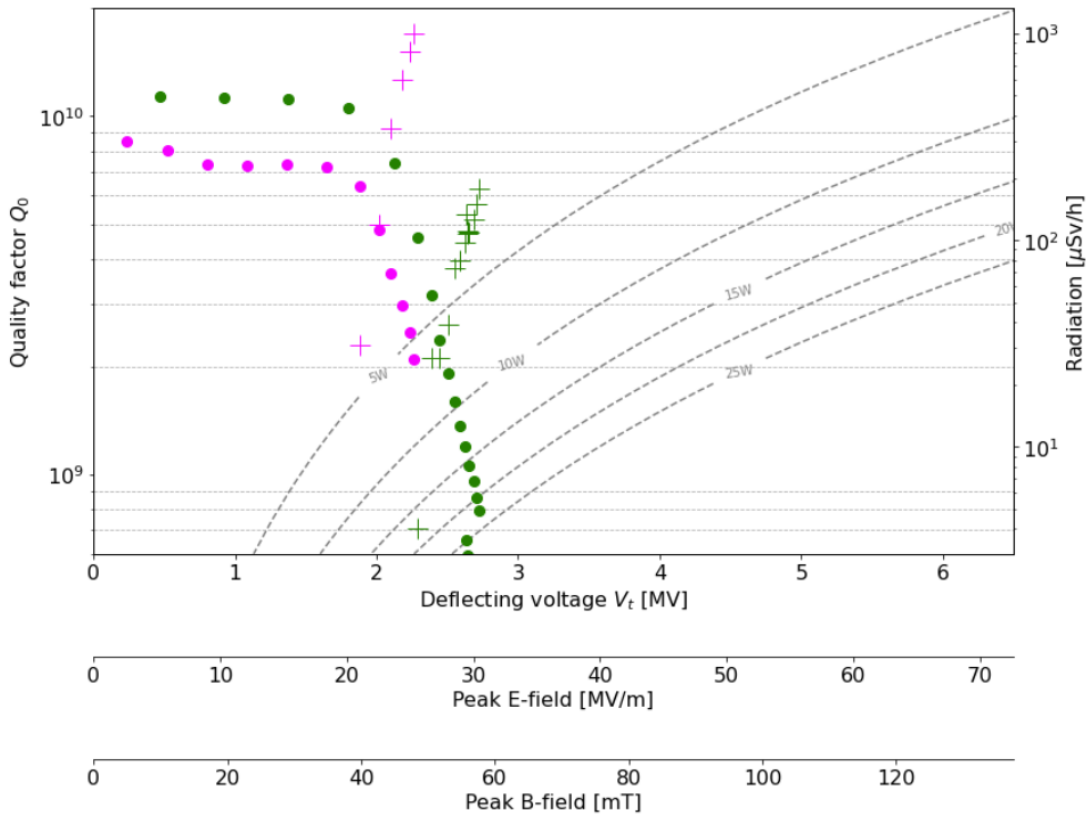

Bare Cavity Test Results – DQW1-RI-BC

- Tested three times:
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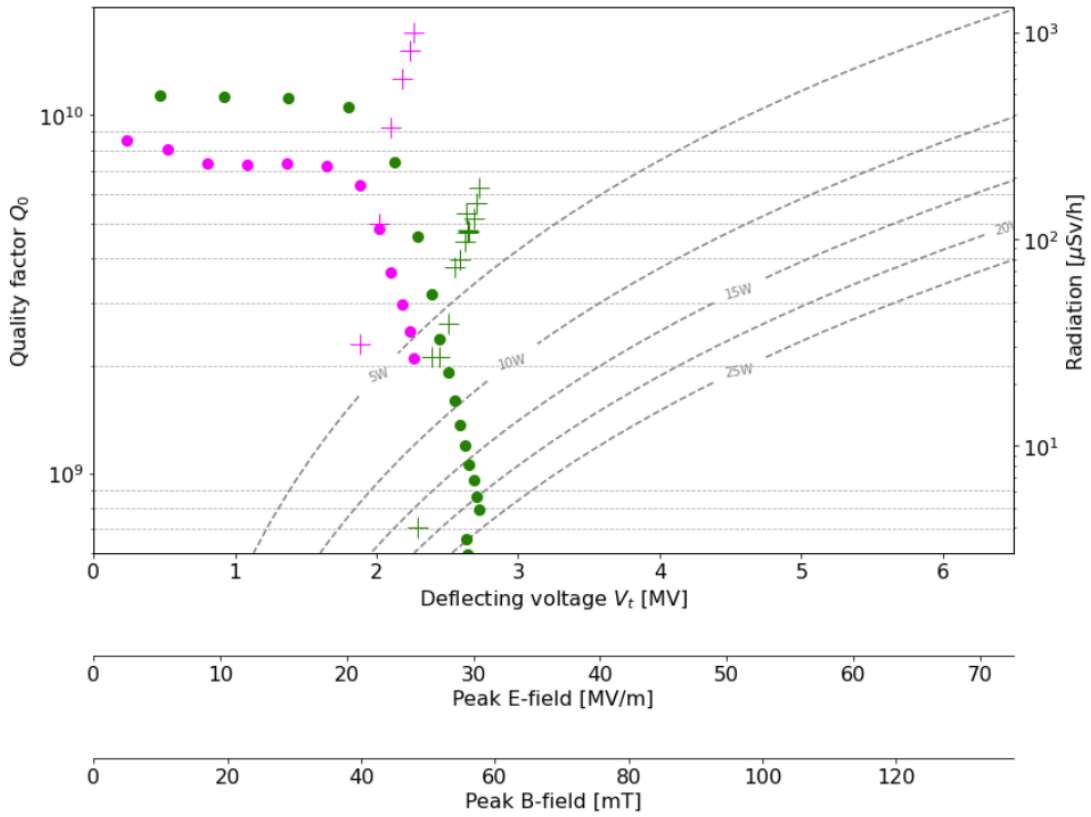
  - **2nd CT** after HPR at CERN stopped due to the radiation
  - **3rd CT** after light BCP (~30µm) at CERN: met specification
    - **5.8MV** (Q0=1.6e9), Epeak~65MV/m and Bpeak~122mT



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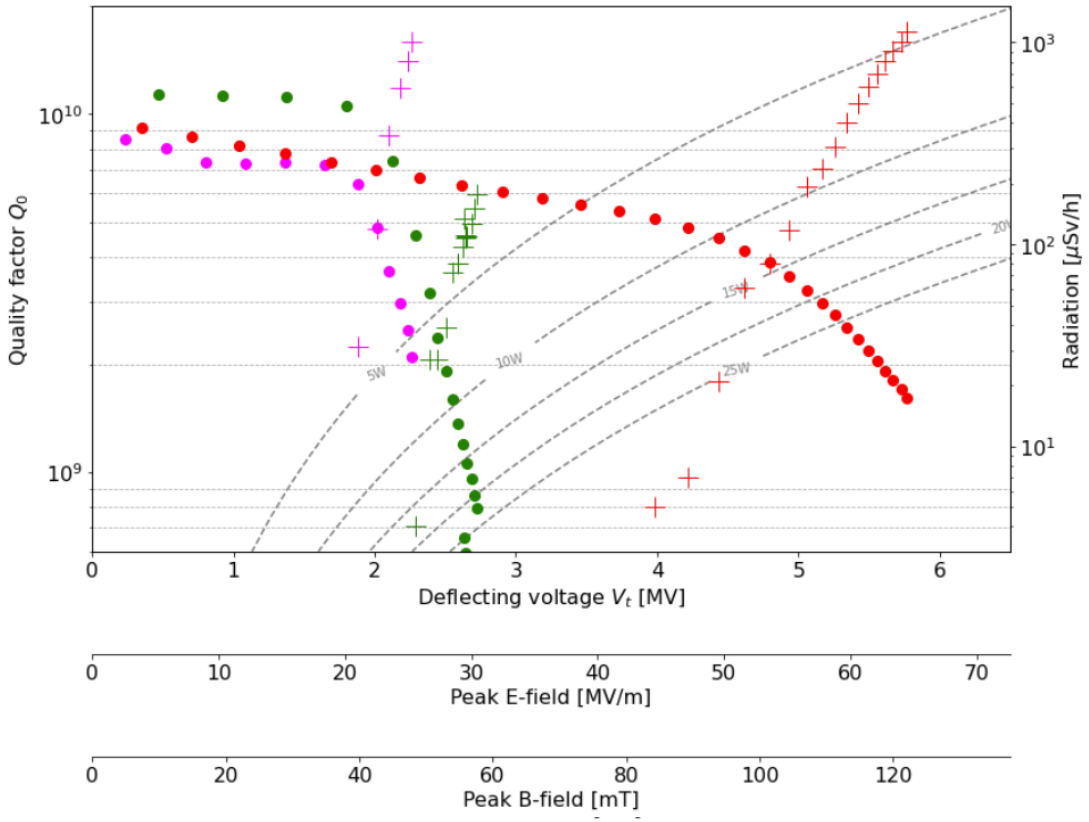
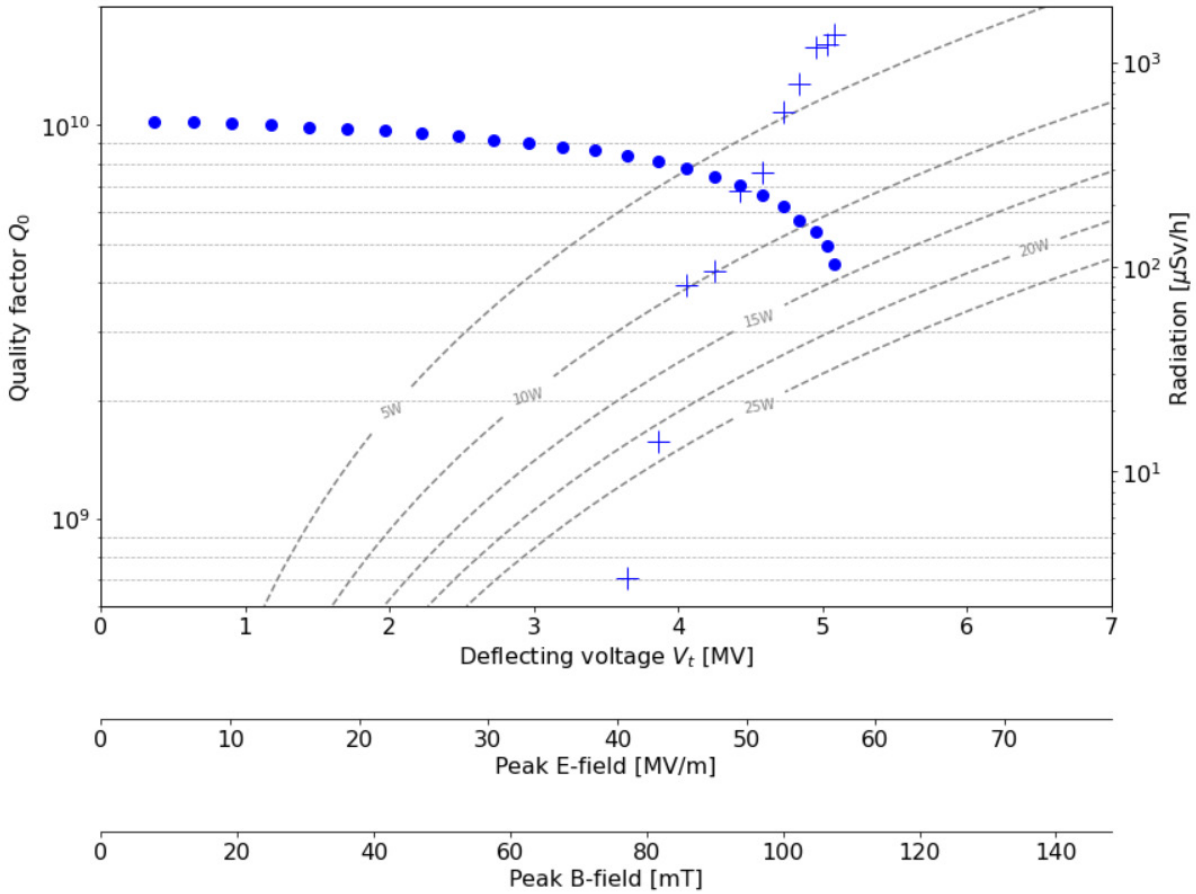


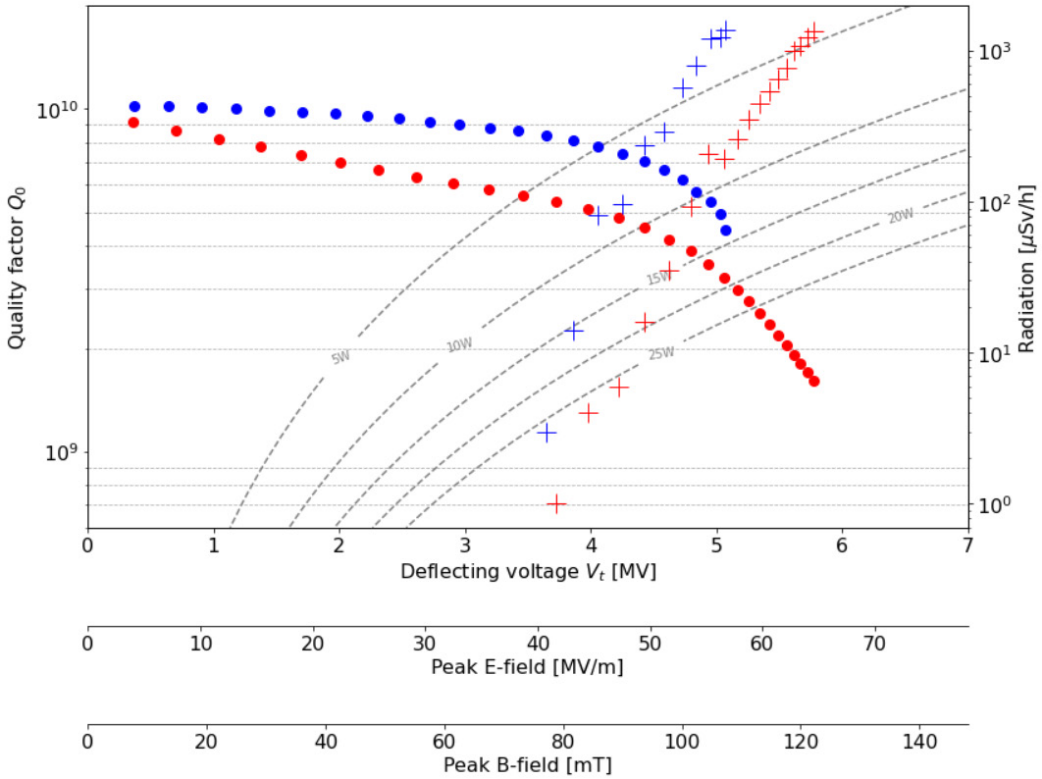
Bare Cavity Test Results – DQW2-RI-BC

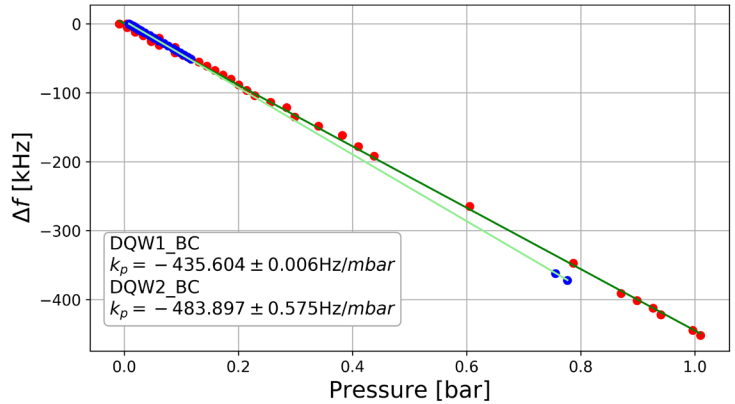
- **DQW2: 5MV** (Q0=5e9), Epeak~57MV/m and Bpeak~108mT
  - Test stopped at 5MV → because of the radiation but no quench observed



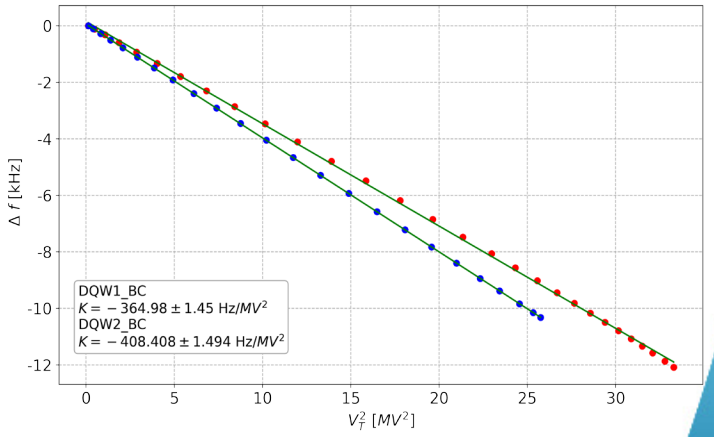
Bare Cavity Test Results – DQW1-RI-BC & DQW2-RI-BC

- **DQW1: 5.8MV** (Q0=1.6e9), Epeak~65MV/m and Bpeak~122mT
  - Tested 3 times: light BCP at CERN (~30µm) to recover the RF performance
- **DQW2: 5MV** (Q0=5e9), Epeak~57MV/m and Bpeak~108mT
  - Test stopped at 5MV → because of the radiation but no quench observed
- The cavities were sent to RI for jacketing





Pressure sensitivity



Lorentz Force Detuning

DQW series cavity built by CERN

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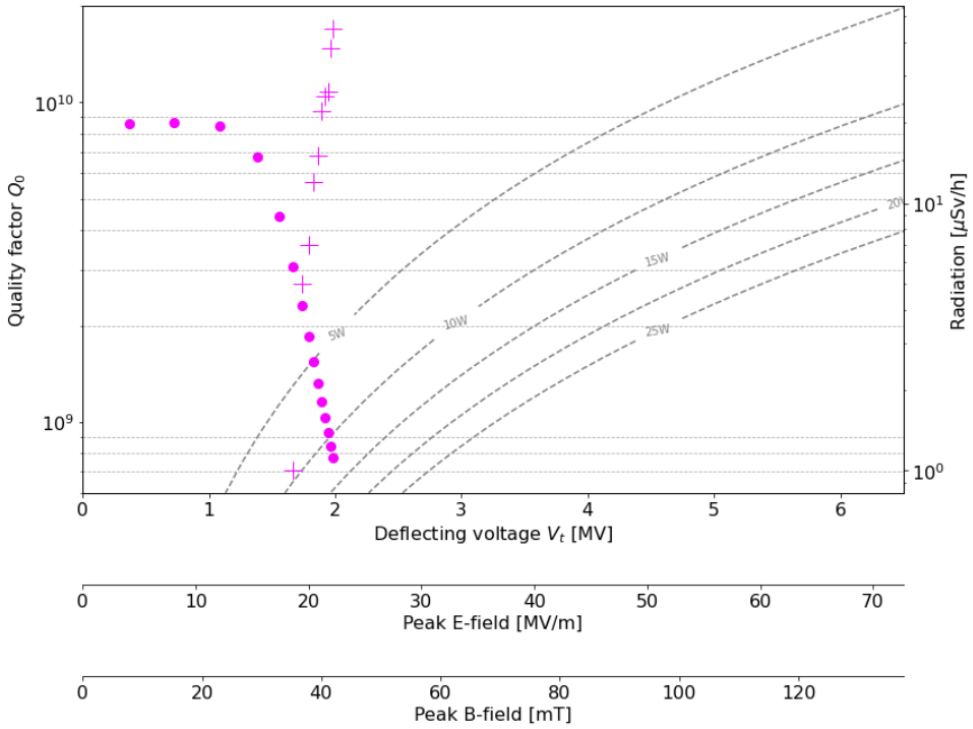

Bare Cavity Test Results – DQW1-CERN-BC

- Tested three times:
  - **1st CT** poor RF performance test stopped
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    - Before He processing
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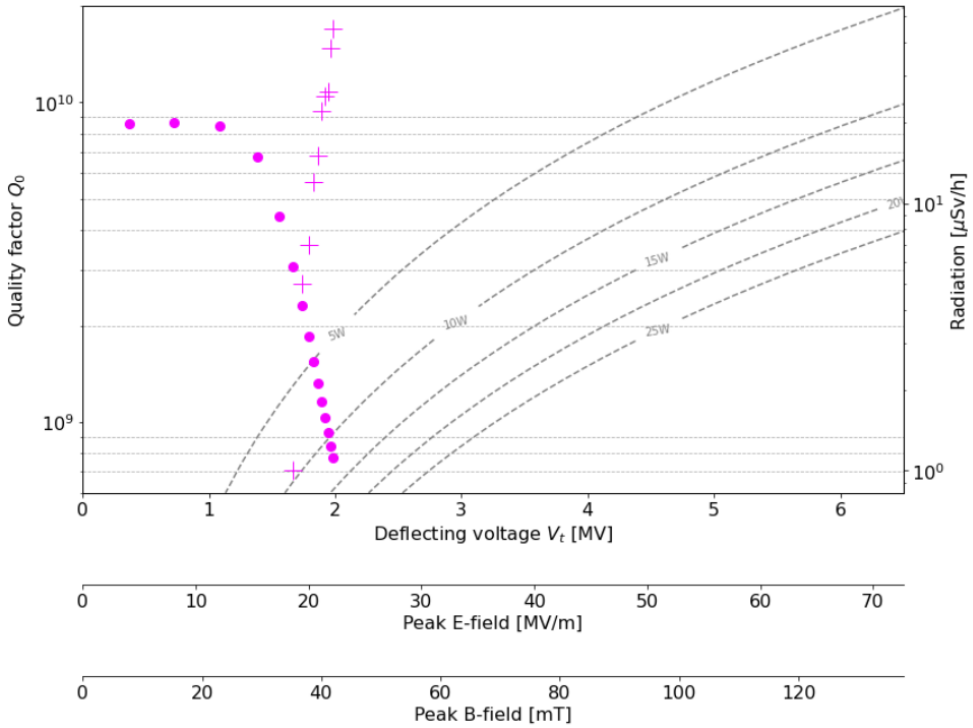

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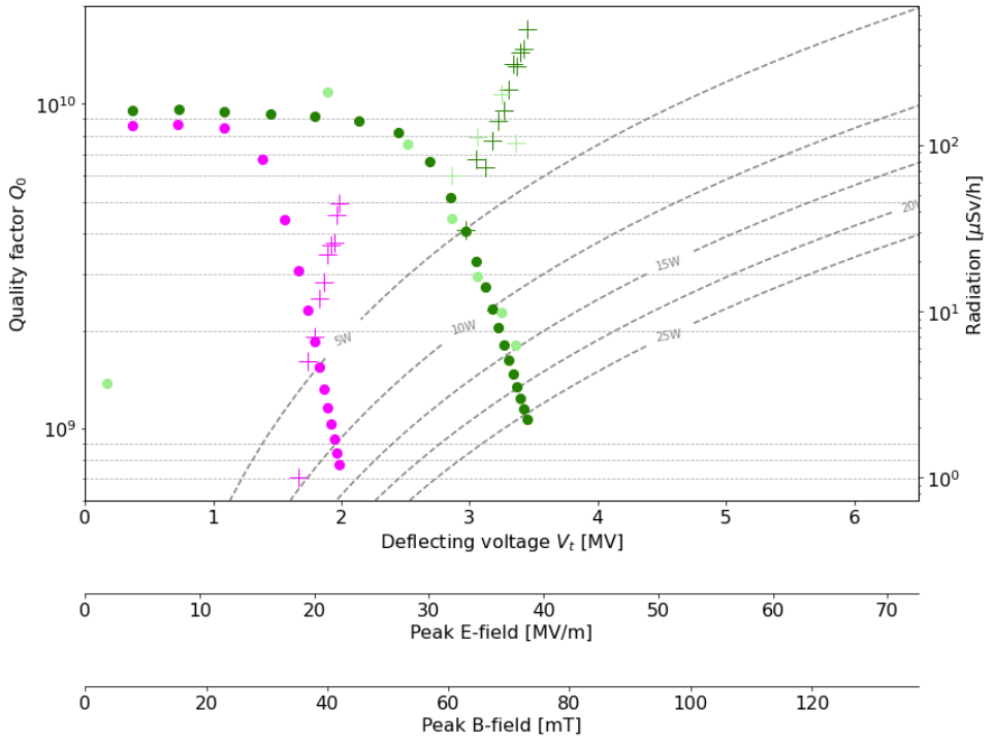

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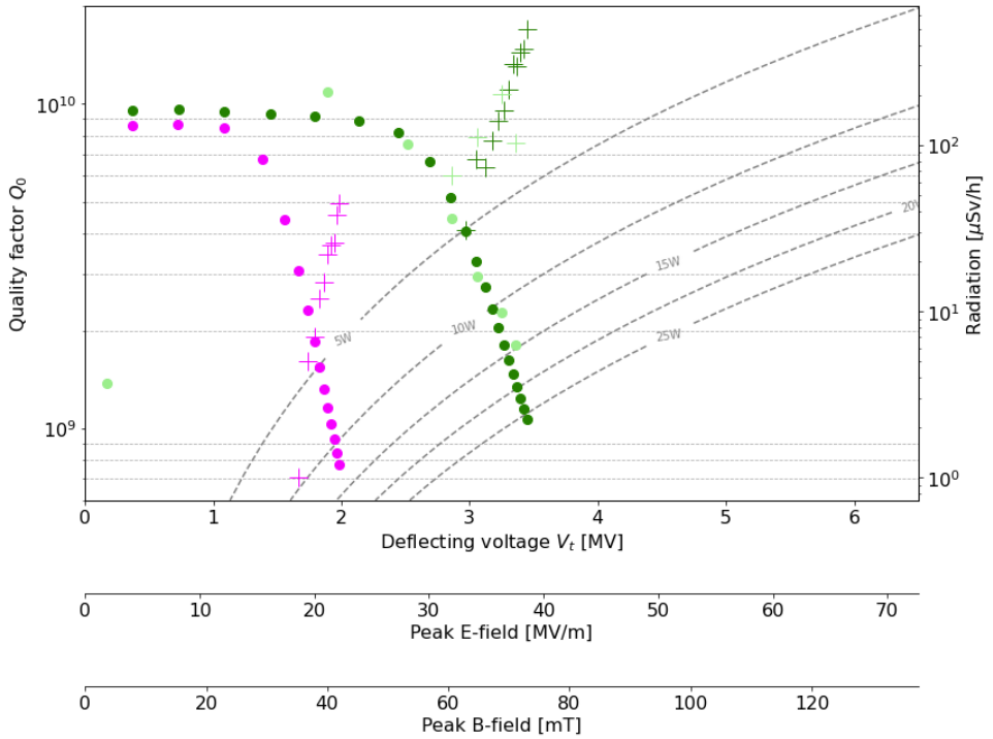
  - 3rd CT after additional light BCP (~30µm): met specification
    - **5.6MV** (Q0=2e9), Epeak~63MV/m and Bpeak~119mT



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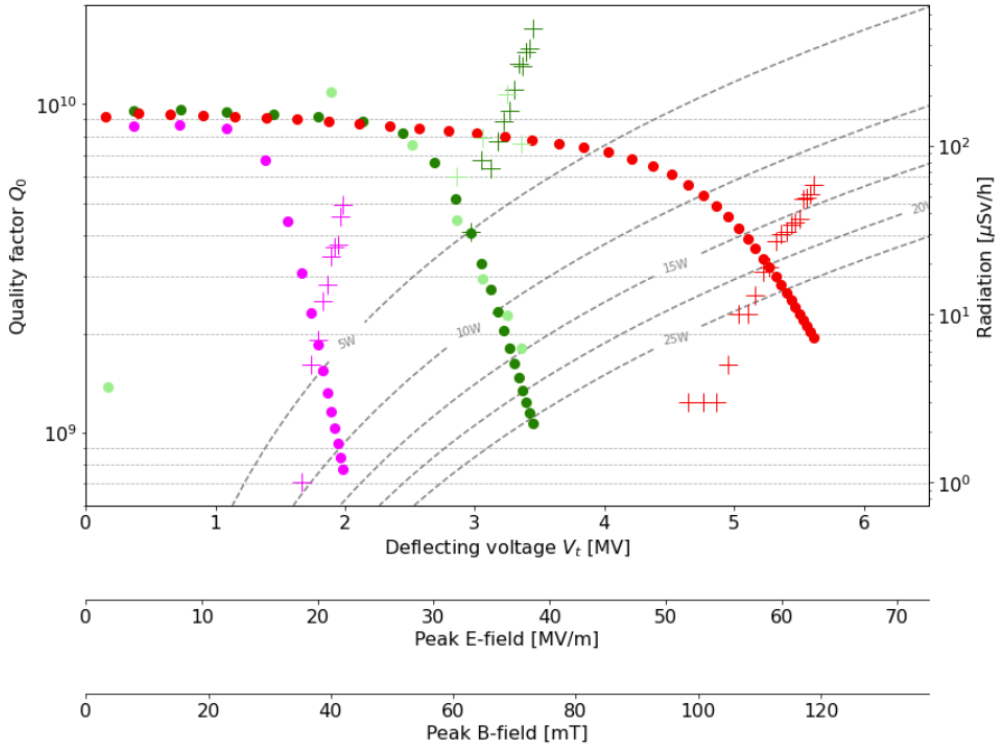
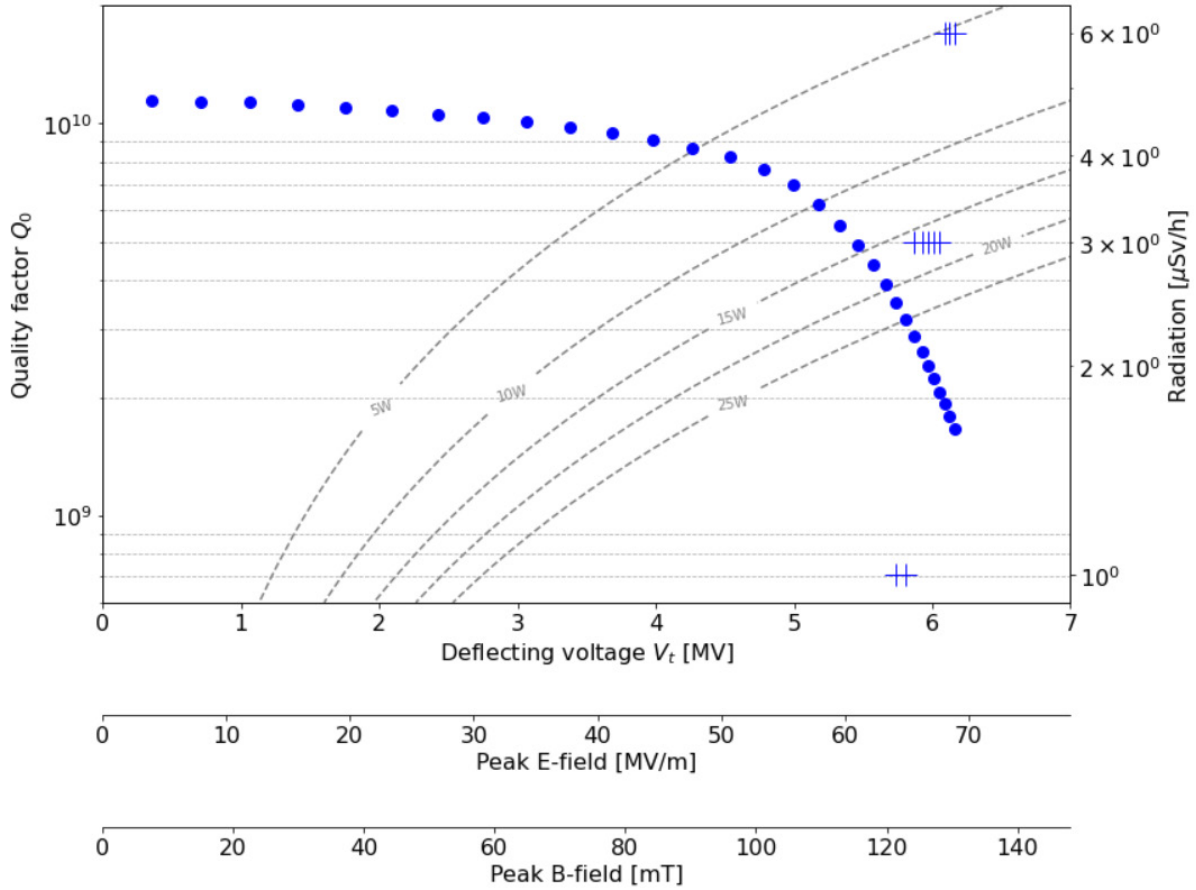


Bare Cavity Test Results – DQW2-CERN-BC

- **DQW2: 6.17MV** (Q0=1.7e9), Epeak~69MV/m and Bpeak~130mT



Bare Cavity Test Results – DQW1-C-BC & DQW2-C-BC

- **DQW1: 5.6MV** (Q0=2e9), Epeak~63MV/m and Bpeak~119mT
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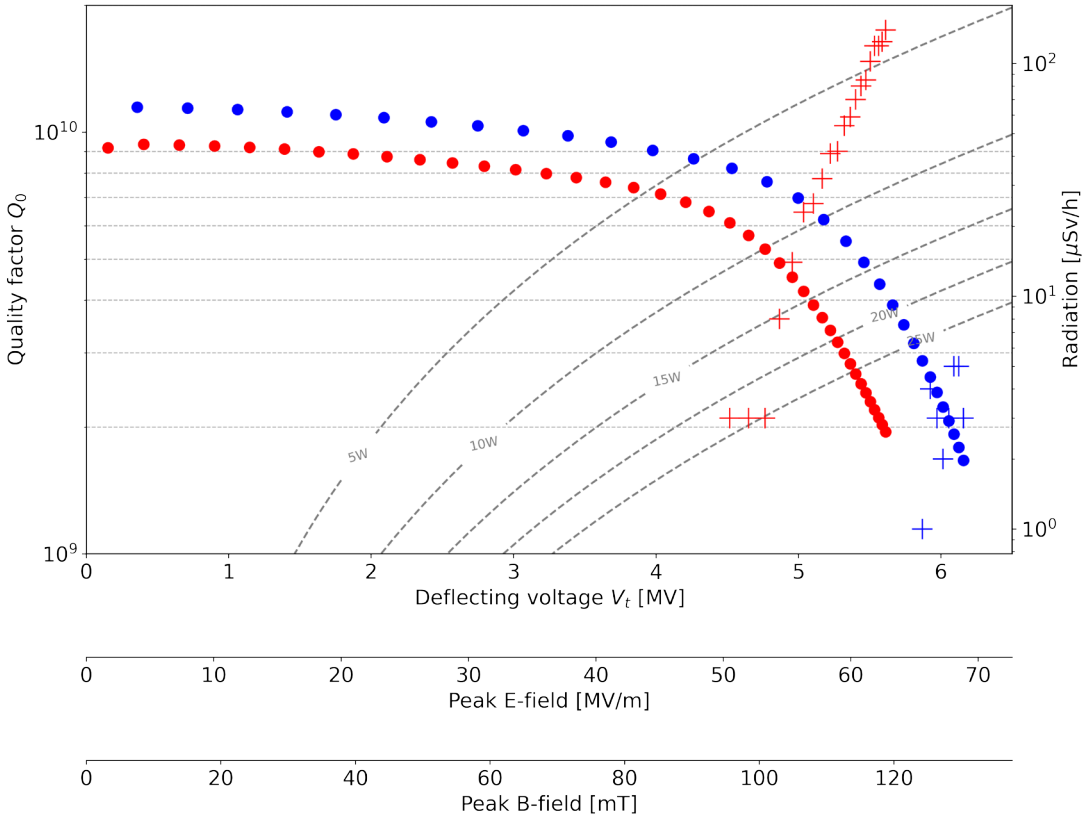
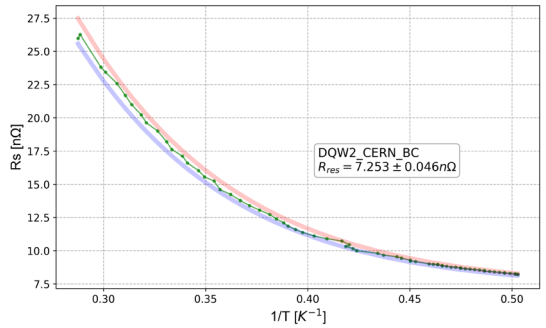
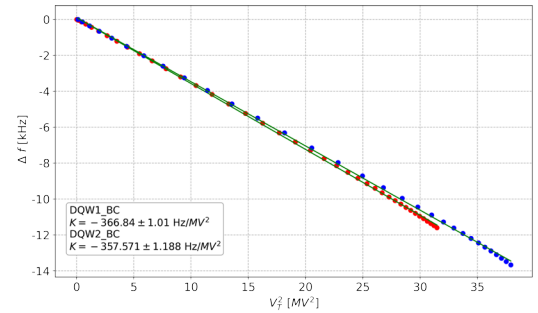
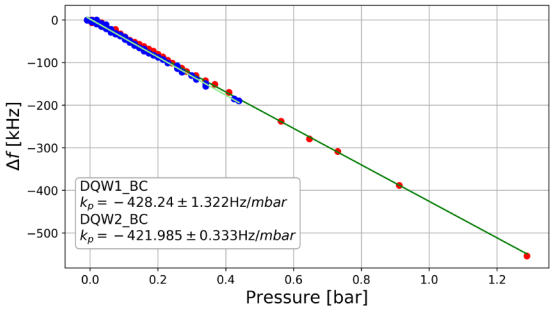




Residual resistance: ~7.3nΩ



Lorentz Force Detuning

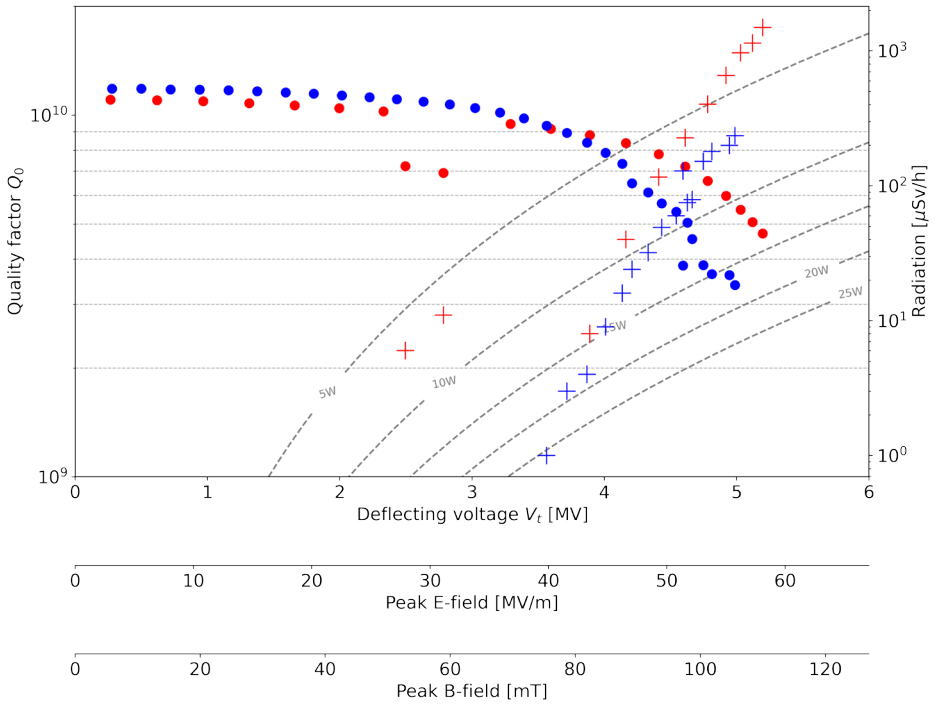


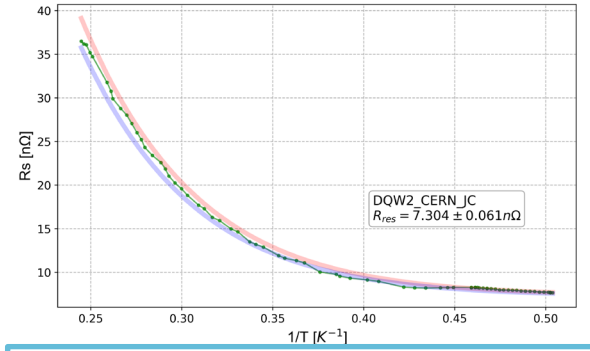
Pressure sensitivity

Jacketing: Cold Magnetic Shield + Helium tank assembly (bolted) and TIG welding

Jacketed Cavity Test Results – DQW1-CERN & DQW2-CERN

- **DQW1: 5.1MV** (Q0=5e9), Epeak~67MV/m and Bpeak~108mT
- **DQW2: 5 MV** (Q0=3.4e9), Epeak~56MV/m and Bpeak~106mT
- Thermal cycle (~20K) consistently improved Q0
  - ~400% for jacketed configuration
- Test stopped at ~5MV
- The cavities were sent for dressing at CERN





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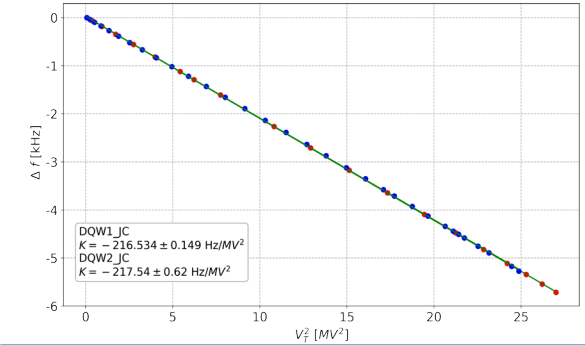
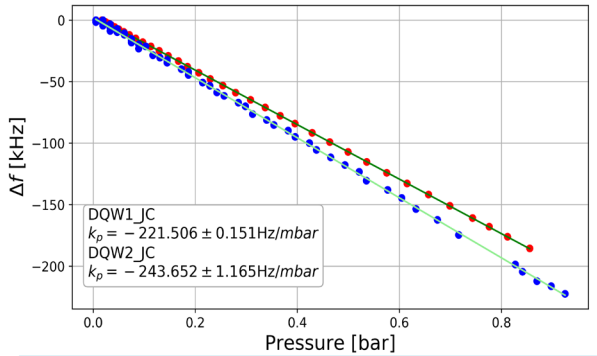


Lorentz Force Detuning



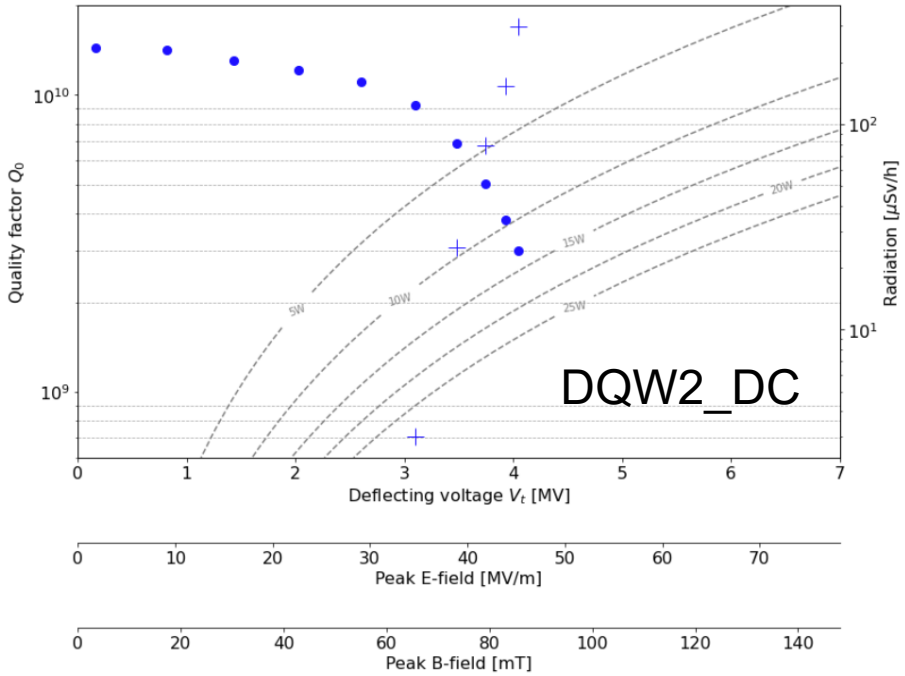
Pressure sensitivity

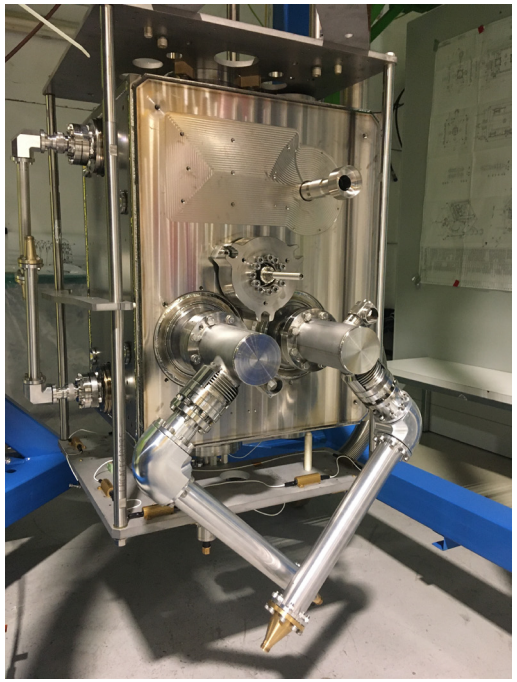
Dressing: JC equipped with all HOMs and FA

- LPR of HOMs and FA
- Clean room assembly with dedicated tooling

Dressed Cavity Test Results – DQW1-CERN & DQW2-CERN

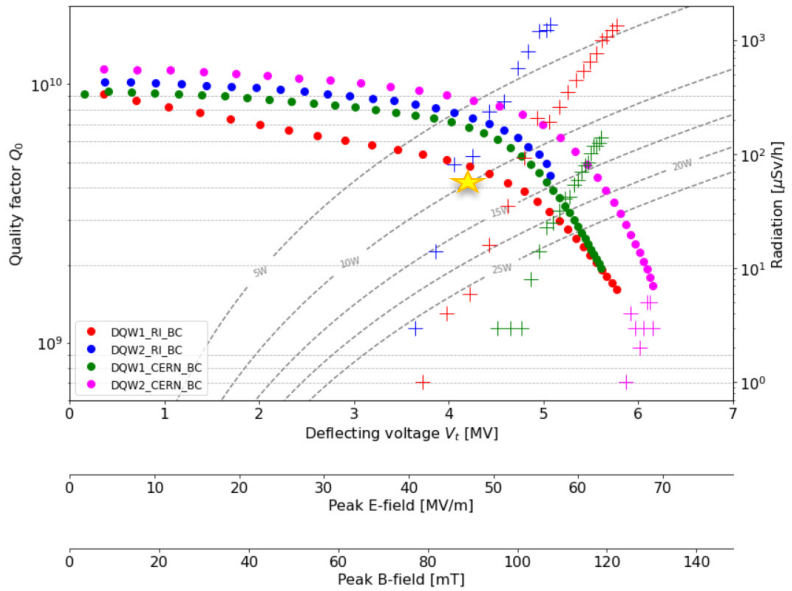
- DQW1 and **DQW2** were tested fully dressed and both reached 4MV (close to the specification value for a dressed cavity).
- Ongoing investigations into field limitations above 4MV to try and surpass the specification.
- 25Ω feed-throughs + adapters were implemented and posed no issue.

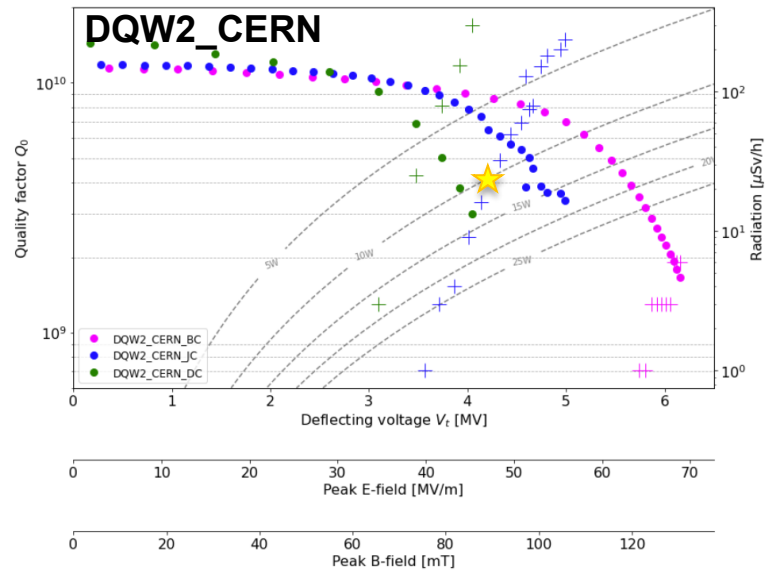




Conclusions

- Two bare cavities from RI were delivered and met the requirements.
- Two CERN built DQW cavities reached the specification target in bare and jacketed configuration
  - Record performance and repeatability achieved
- Several important lessons were learned during the testing of the DQW cavities.
  - The max field reached are almost always dominated by the presence of field emission
  - Thermal cycle, up to ≈20 K, consistently improved the $Q0$ of both the jacketed and dressed cavities by ≈400%
  - We observe a reduction in the maximum field achieved by the cavity, as the complexity of the cavity configuration increases through the stages of the VCTs





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Thank you very much!