DQW HOM Measurements, Analysis and Application

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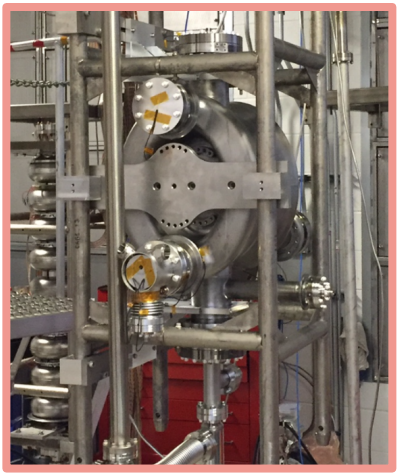
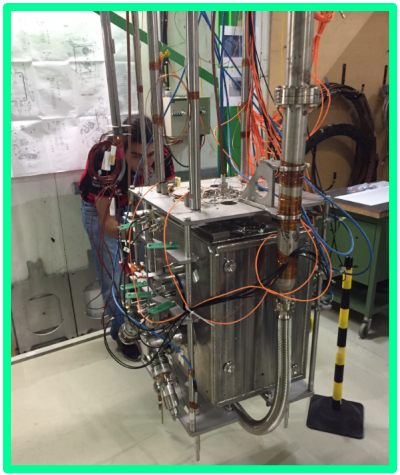
Introduction

- Tests of the DQW with HOM couplers.
  - Measurements taken.
  - Measurement deviation from simulations.
- Impedance and power for HL-LHC.
  - Current scenario.
  - Mode tolerance study.
- HOM coupler design re-visited.
  - Damping the impedance below the threshold.
  - New spectral power.

DQW Tests with HOM Couplers

No of HOM Couplers	Cavity	Helium Vessel?
1	NWV-DQW-001	N
3	CERN-DQW-001	Y
1	NWV-DQW-002	N

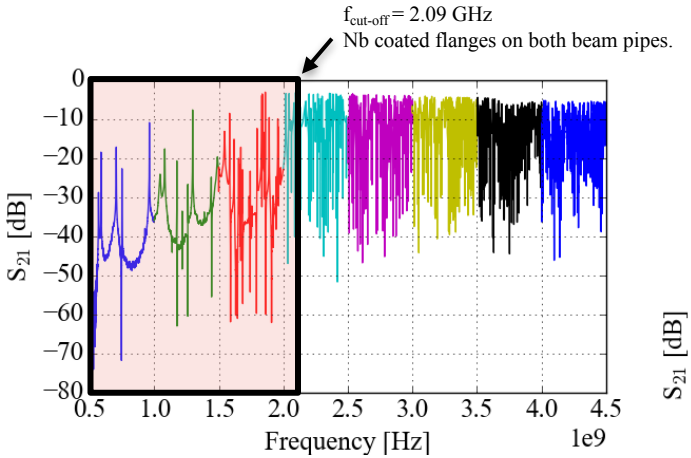


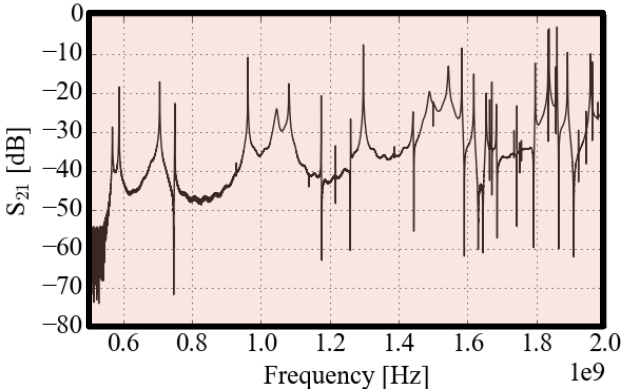


DQW Tests with HOM Couplers

JLAB Spectral Measurements

- S_{21} measurements between HOM coupler and cold test Power Coupler (PC).
- Temperatures: 300, 4.5 and 2 K.
- Discrete frequency bands taken and stitched for increased resolution.

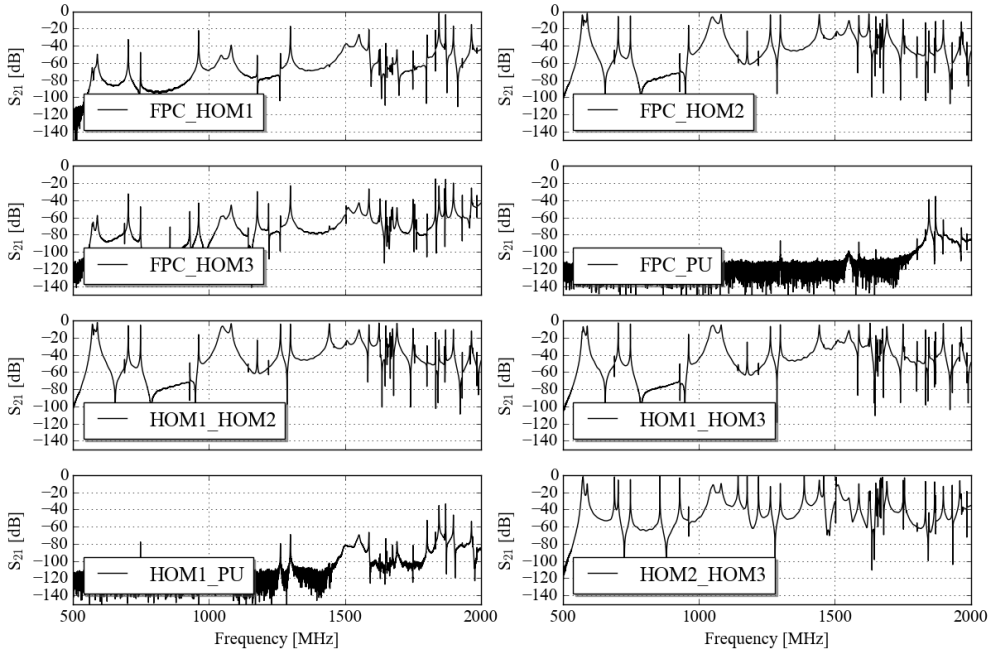




DQW Tests with HOM Couplers

CERN Spectral Measurements

- 5 ports with couplers (PC, PU, HOMC1, HOMC2, HOMC3).
- 8 port configurations measured to measure all modes.
- Temperatures: 300 and 2 K.
- Discrete frequency bands taken and stitched for increased resolution.

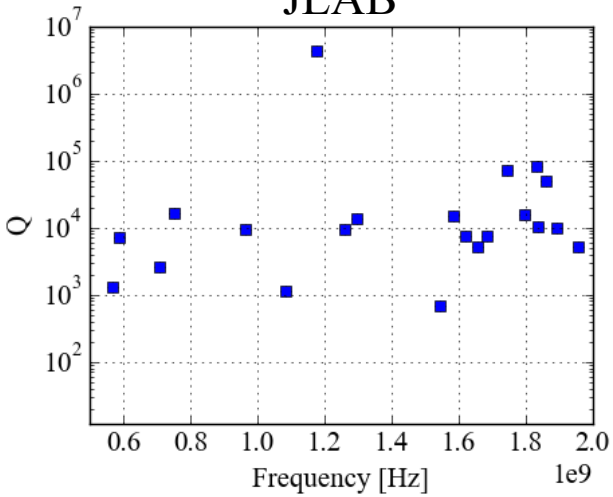


DQW Tests with HOM Couplers

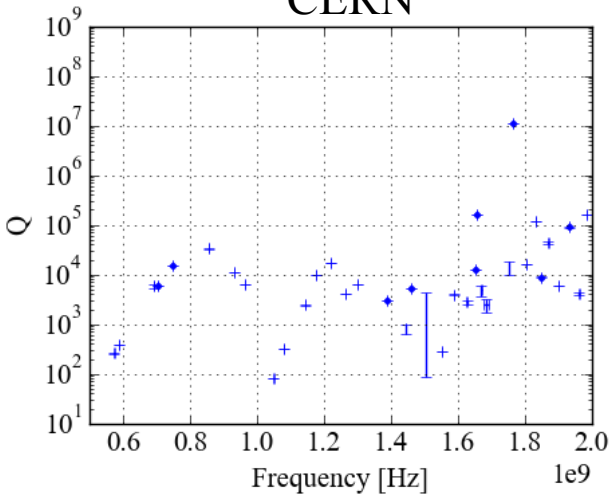
HOM Measurements

- Narrow frequency bands measured at centre frequency of mode.
- Frequency and Q-factor recorded using Lorentzian fit function.

JLAB



CERN



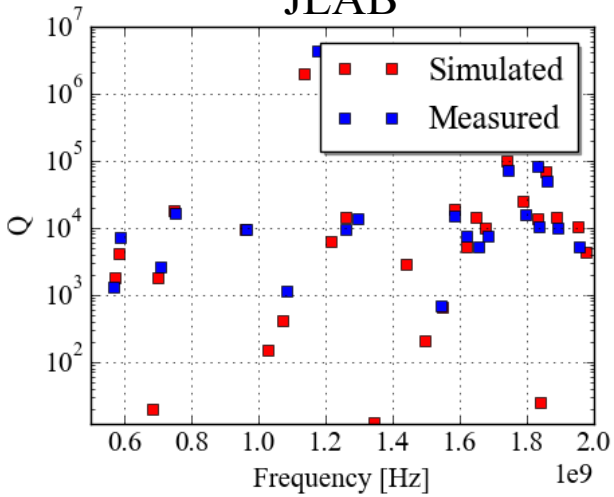
DQW Tests with HOM Couplers

HOM Measurements

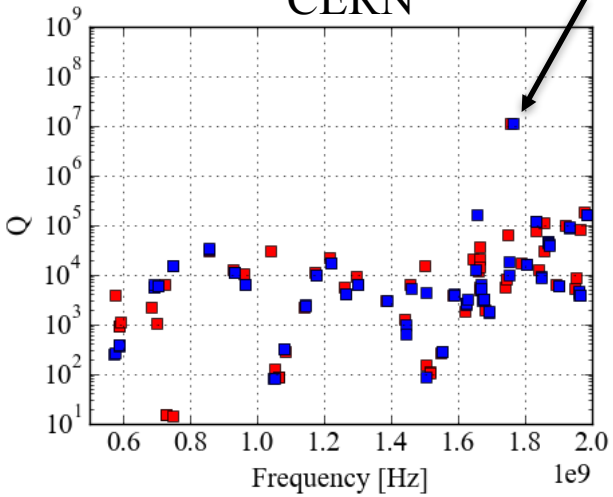
- Narrow frequency bands measured at centre frequency of mode.
- Frequency and Q-factor recorded using Lorentzian fit function.

SPS pick-up not used.

JLAB



CERN



*JLAB cavity is **not tuned** to the correct fundamental frequency.*
f_0 = 403 MHz

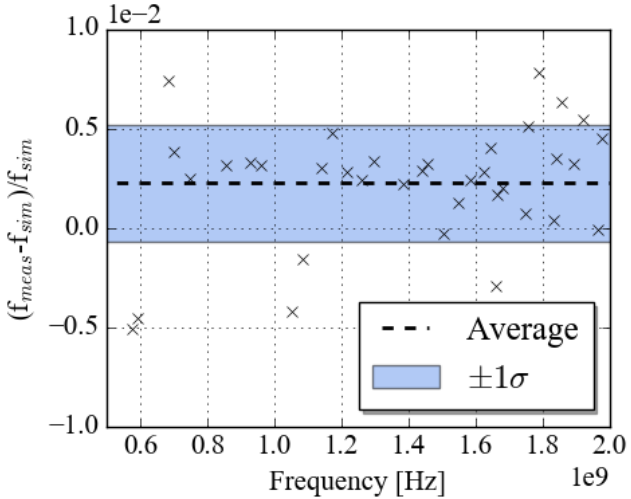
Cavity has +5mm retraction on all HOM couplers (non-conformity error) [1].
Simulation takes this into account.

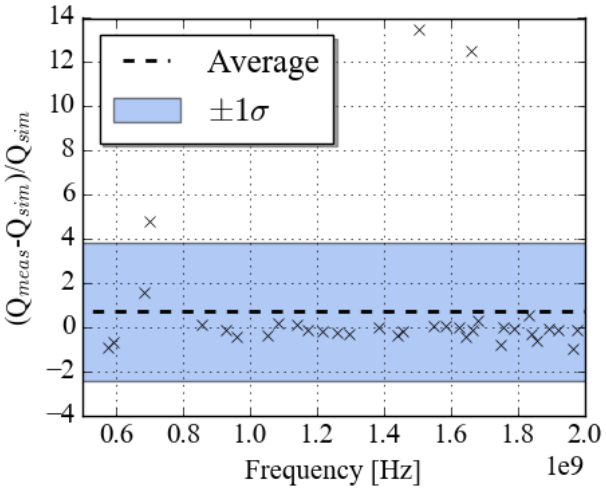
Possible source of error:

- *Non-conformity is not exactly +5mm on all ports.*
- *Cold test power coupler and pick-up may perturb some modes.*

Frequency and Q Spread

- Deviation in measured mode parameters from simulated for CERN-DQW-001 partially dressed test.
- Mode tolerances for impedance, power and beam stability simulations.





- $\frac{f_{meas} - f_{sim}}{f_{meas}} = 0.00224 \pm 0.00294$
- $\frac{Q_{meas} - Q_{sim}}{Q_{meas}} = 0.711 \pm 3.12$

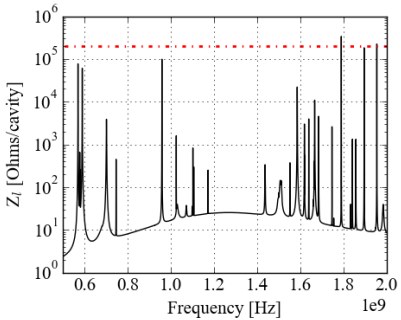
For reference
At 0.5 GHz: $\Delta f = 1.12\ MHz$
At 1.5 GHz: $\Delta f = 3.36\ MHz$

The spread should be applied as a tolerance study. To do this the current impedance and power spectra should be noted.

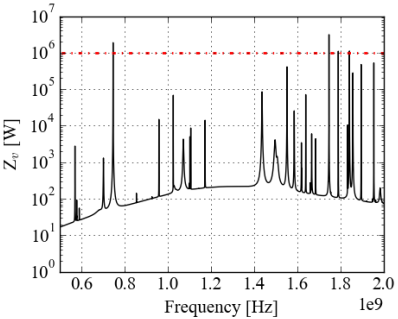
Analytical Tolerance Study

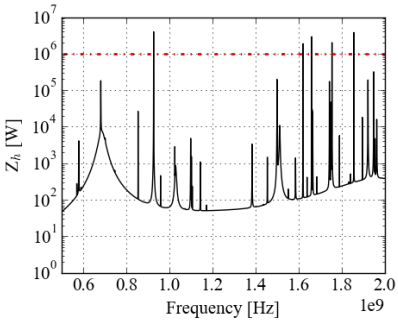
Cavity Impedance Spectra

- Impedance spectra calculated in order to calculate the power.
- Currently some modes are above thresholds.



Impedance Thresholds
Longitudinal: 200 kΩ/cavity
Transverse: 1 MΩ/m/cavity

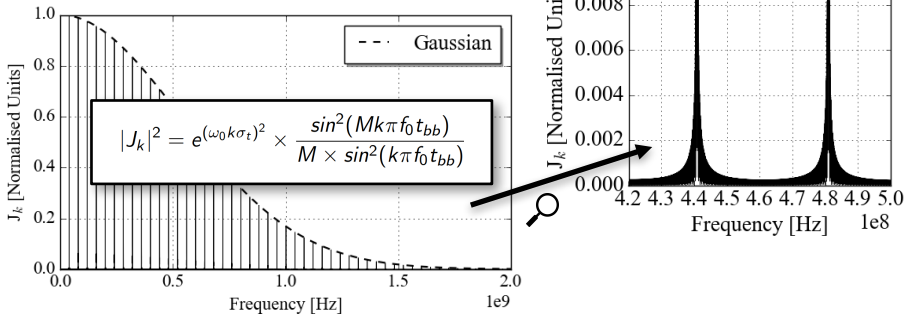


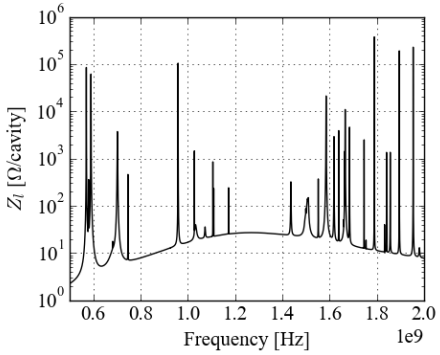


Analytical Tolerance Study
Cavity Power Spectra

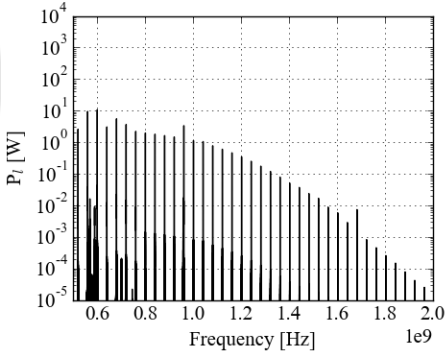
- Resulting longitudinal power from HL-LHC parameters calculated.

Parameter	Value
Machine	HL-LHC
Bunch profile	Gaussian
Number of bunches, M	2748
Particles per bunch, N_p	2.2E11
Harmonic number, h	35640
RF frequency, f_{RF}	400.8 MHz
Bunch length (4σ), σ_t	1.2 ns
Bunch spacing, t_{bb}	24.95 ns





$$P_{(x,y,z)} = 2 \times I^2 Z_{(x,y,z)} \times |J_k|$$



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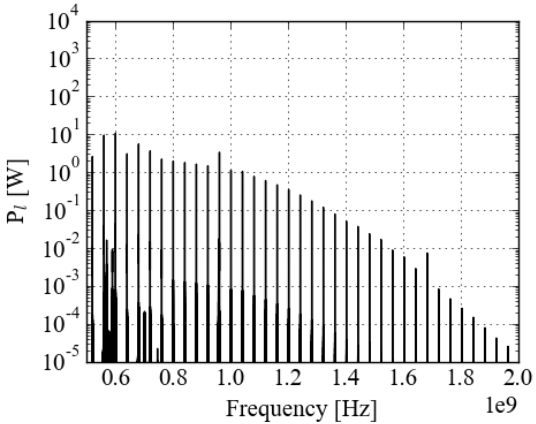
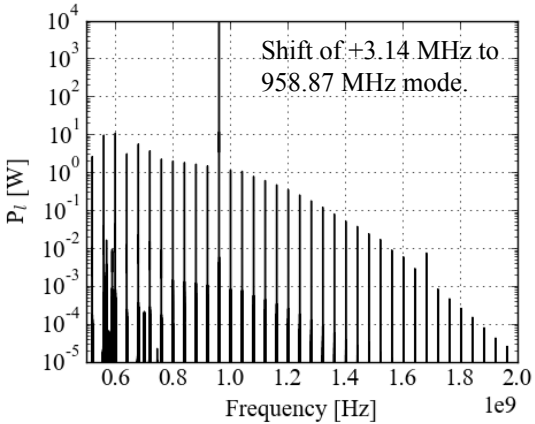
Analytical Tolerance Study
Problematic Mode

- Applying a frequency offset to the modes shows that there is one mode solely capable of substantially increasing the power.

Frequency shift of 0.3% of 958.87 MHz mode

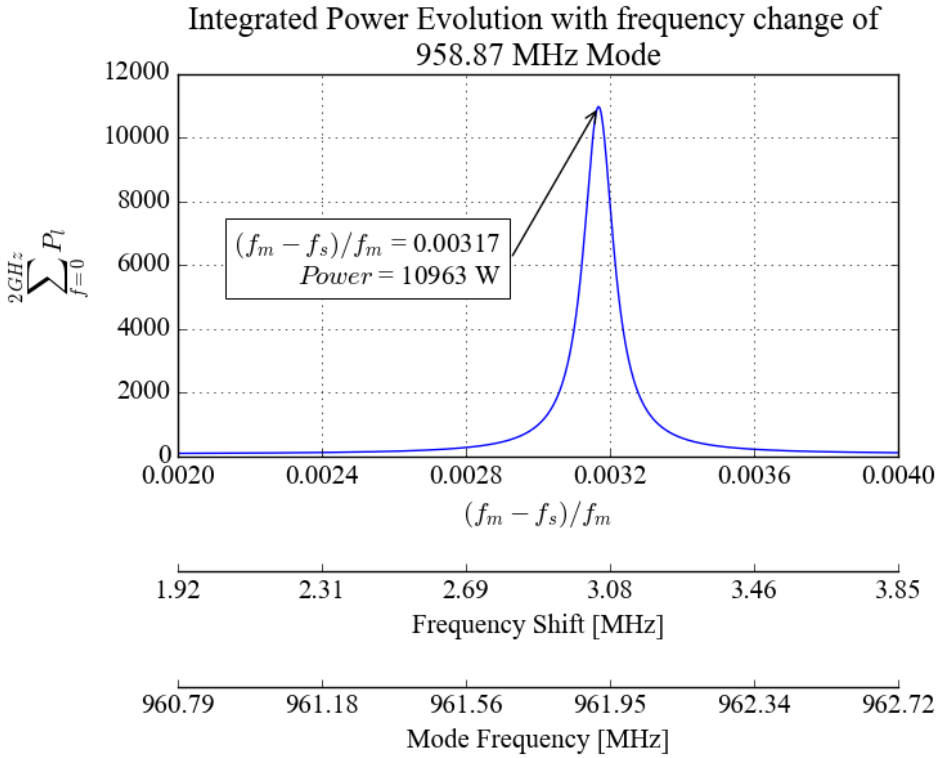




- From the spread quantified, this corresponds to: = 0.00317
  - This value is within the measured spread of 0.00224 ± 0.00294
- The frequency of this mode in CERN-DQW-001 was 962.25 MHz
  - 330 kHz above spectral line frequency.
- From the cold → warm shift of -1.45 MHz observed the current predicted frequencies at cold are: **962.034 and 962.253 MHz** respectively for **SPS cavity 1 and 2** using warm measurements on the string assembly.

Analytical Tolerance Study
Problematic Modes

- From the cold → warm shift of -1.45 MHz observed the current predicted frequencies at cold are: **962.034 and 962.253 MHz** respectively for **SPS cavity 1 and 2** using warm measurements on the string assembly.



What power would result in HL-LHC?

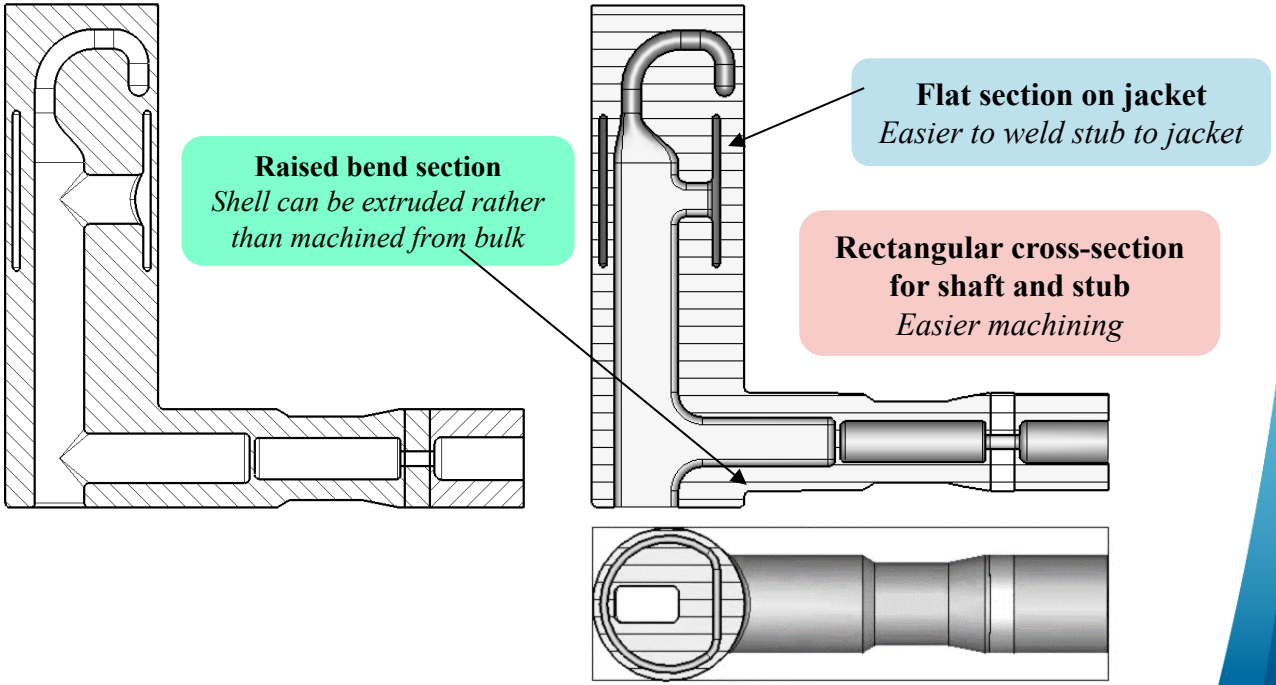
962.034 MHz
1727 W

962.253 MHz
309 W

*The mode frequencies have risen past the worst case scenario – showing feasibility of the 11 kW power generation.

HOM Coupler Design Changes

- HOM coupler improvements:
  - **Improve the ease of manufacture.**
  - Damp impedance thresholds to below the documented thresholds.
  - Further damp the mode at 959 MHz → reduce power below 1 kW.

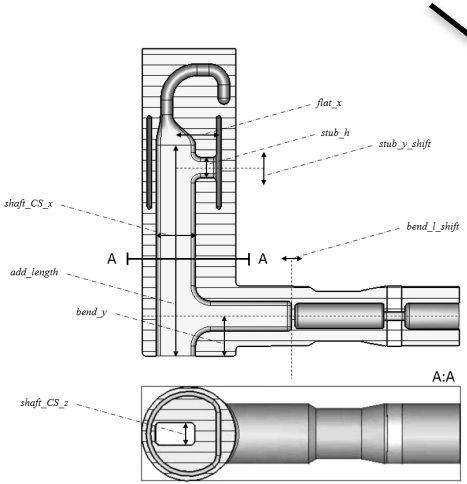


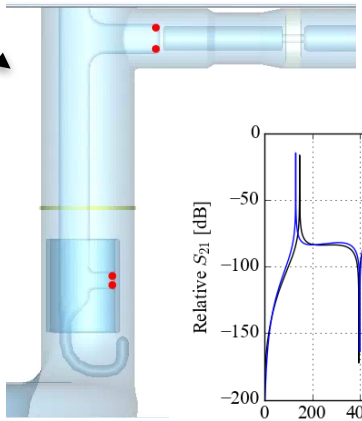
HOM Coupler Design Changes

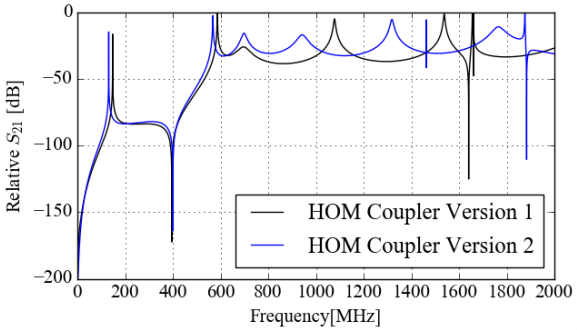
RF Improvements

- HOM coupler improvements:
  - Improve the ease of manufacture.
  - **Damp impedance thresholds to below the documented thresholds.**
  - **Further damp the mode at 959 MHz → reduce power below 1 kW.**

- By altering the geometries of the HOM coupler, the transmission response was altered to better damp modes above the impedance threshold.

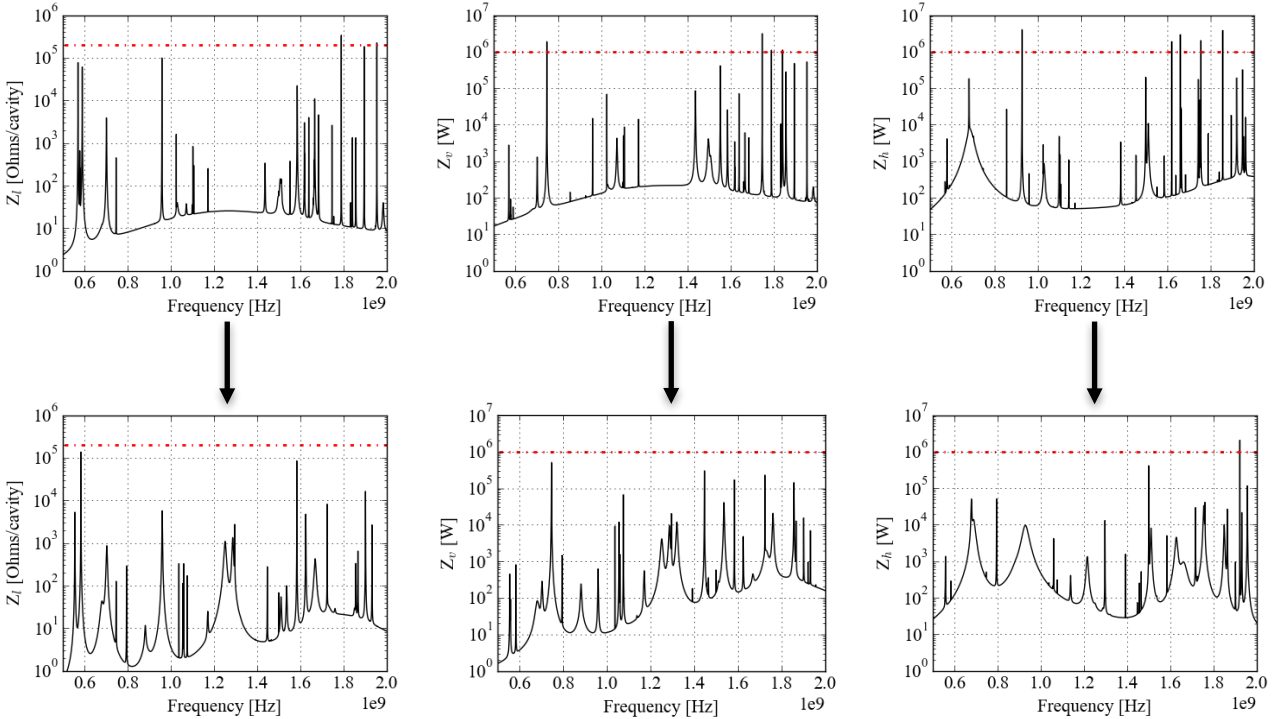






HOM Coupler Design Changes

New Cavity Impedance Spectra

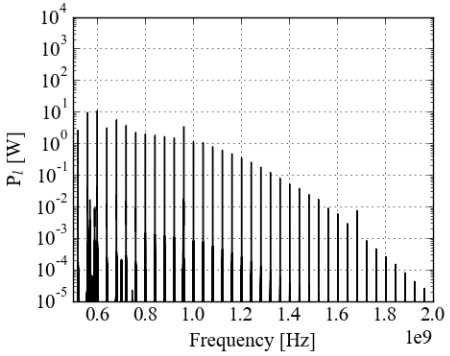
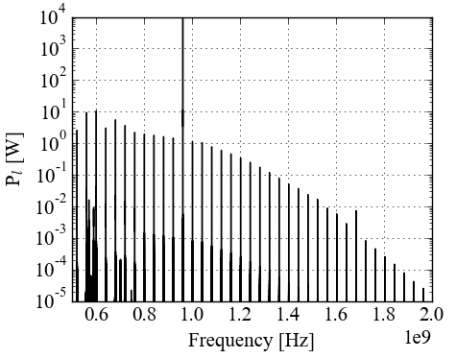
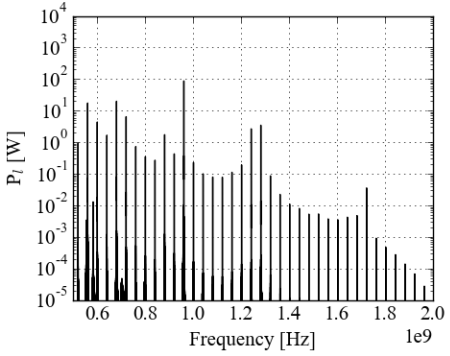
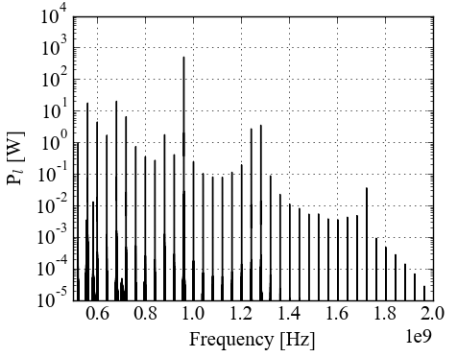


- 959 MHz mode:
  - Q: 1E4 → 0.057E4
  - R_l: 1E5 → 0.056E5

All modes apart from one (1920 MHz) are below threshold.

HOM Coupler Design Changes

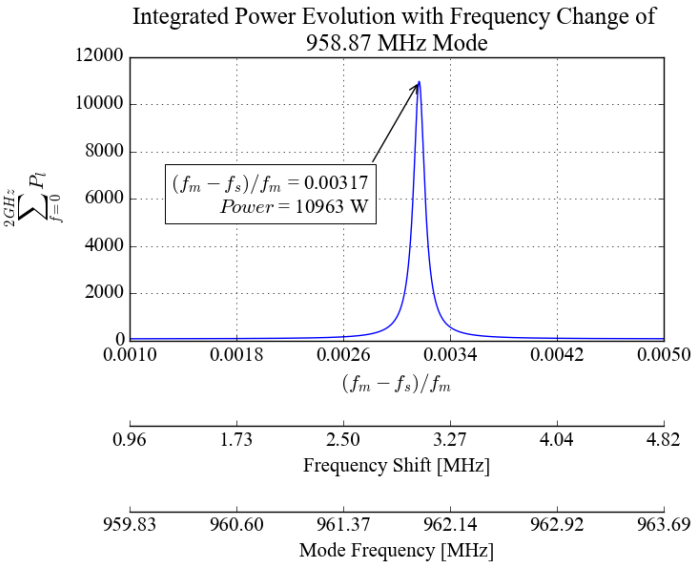
New Cavity Power Spectra

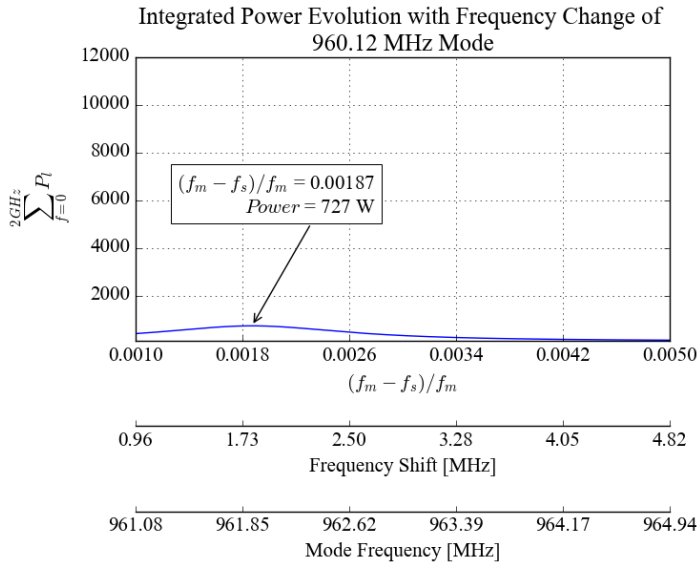
	Nominal	***Detrimental mode shifted***
Current HOM coupler		
New HOM Coupler		

HOM Coupler Design Changes

New power with 960 MHz mode deviation

- Power generated with deviation of the mode at ~ 960 MHz is much lower for the new HOM coupler.
- Frequency has changed slightly meaning that the shift necessary for maximum power has reduced from 0.3% to 0.2%.
- However, the power produced has reduced by a factor of 15.

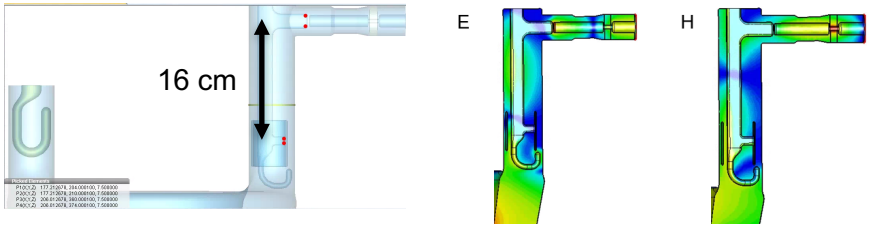




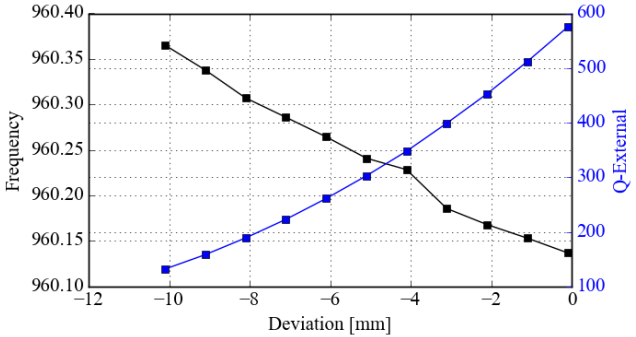
HOM Coupler Design Changes

Further Analysis

- The integrated power with the mode exactly on 960 MHz has reduced from:
  - 11 kW to 742 W
- However, the mode frequency has shifted from 958.87 MHz to 960.1 MHz.
  - At 960 MHz:
  - $\frac{\lambda}{2} = 15.6\ cm$



- Coupler geometries which effect the frequency of this mode are being investigated.

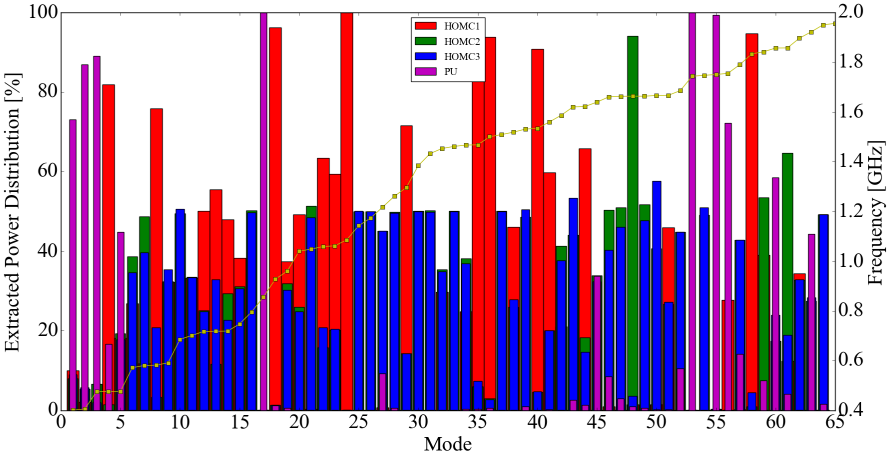


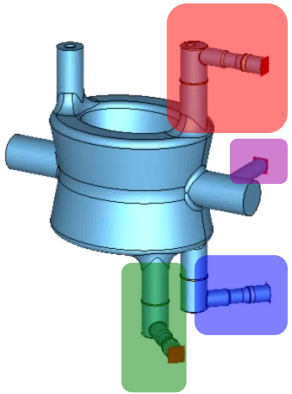
- In addition, it was commented that the distance between the hook and capacitive jacket should be increased. This has now been performed and has a minimal effect on the mode damping.

Power Directionality

- It is important to take into account that mode power is not equally split through each coupler.
- Using the ratio of the external Q-factors corresponding to individual port simulations it is possible to see how the extracted power is distributed.
  - → The simulations assume no power is extracted by the FPC or beam pipes and do not take into account Ohmic losses in the cavity.
- Multiplying the mode impedance by the percentage will give a power spectrum for each coupler.

Using current HOM coupler design:





Conclusion

- Tests of the DQW crab cavity with HOM couplers
- Mode parameter measurements
  - Analysis – deviation from simulated → $\frac{\Delta f}{f} = 0.00224 \pm 0.00294$
- Analysis for HL-LHC
  - Impedance and power calculations.
  - Tolerance study and problematic scenario → Mode at 960 MHz can produce large power.
- HOM Coupler Re-design
  - Manufacture improvements.
  - Meeting the impedance threshold.
  - Reducing the power → 11 kW to 742 W
- Further HOM coupler investigations
  - Shifting the frequency of the 960 MHz mode whilst keeping the spectral damping sufficient.
- Taking into account the power does not ‘split’ evenly.

Questions?

References

1. *Paula Freijedo*, “HL-LHC: Quality - Non Conformity Report ”. EDMS 1759686: https://edms.cern.ch/ui/#!master/navigator/document?P:1771791600:1242869639:subDocs

2. I. Karpov, Beam dynamics studies for FCC-ee, 30 May 2017.

3. F. Caspers et al., IMPEDANCE MEASUREMENT OF THE SPS MKE KICKER BY MEANS OF THE COAXIAL WIRE METHOD, PS/RF/Note 2000-004.