CERN

HOM couplers for crab cavities and challenges

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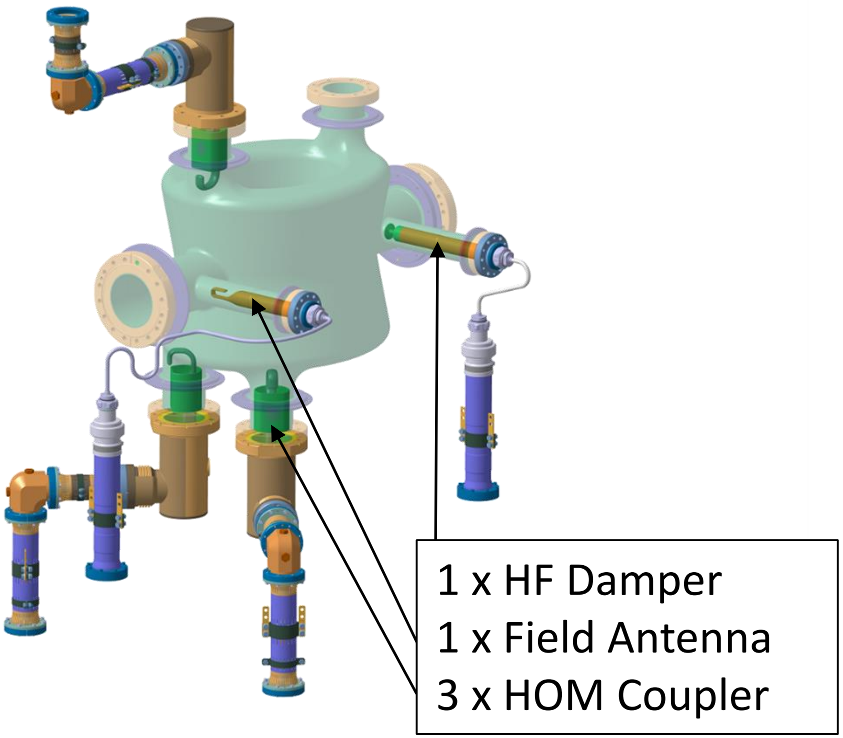
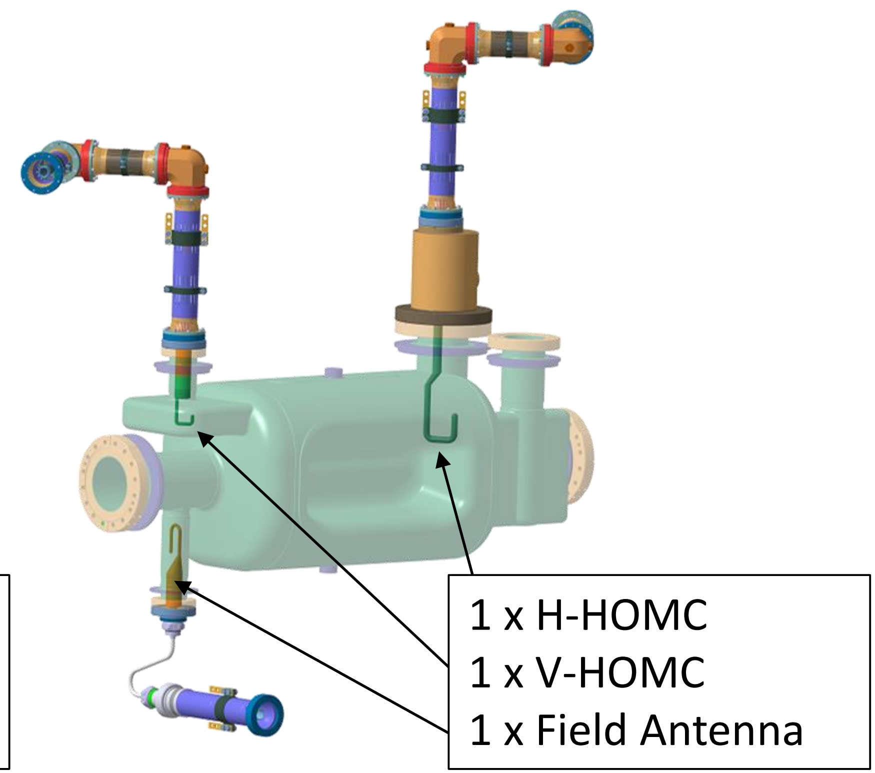
Crab cavity damping

Damping requirements:

$$Z_{\parallel} < 200\ k\Omega$$
$$Z_{\perp(x,y)} < 1\ M\Omega/m$$



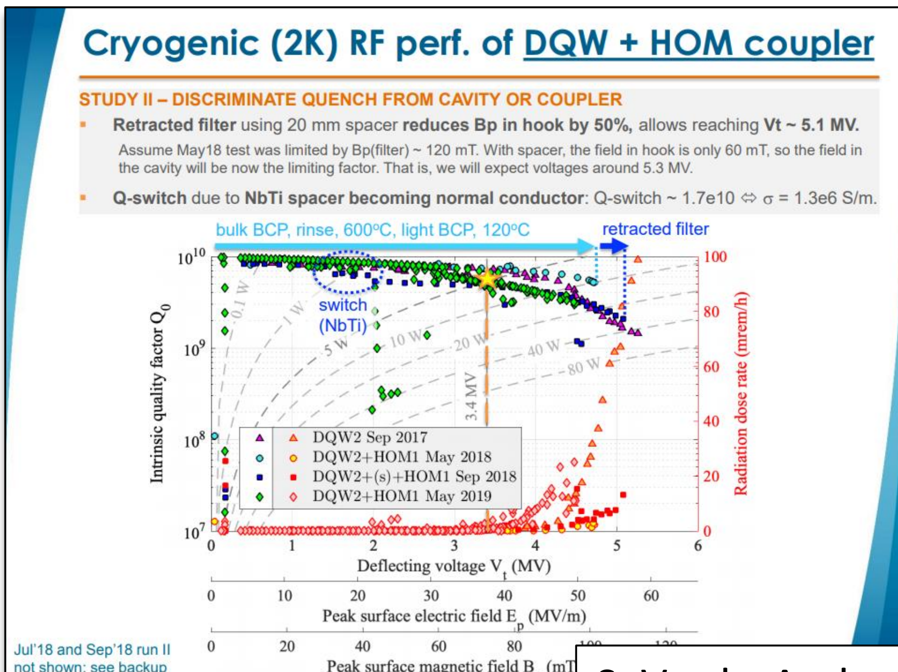
Double Quarter Wave (DQW)



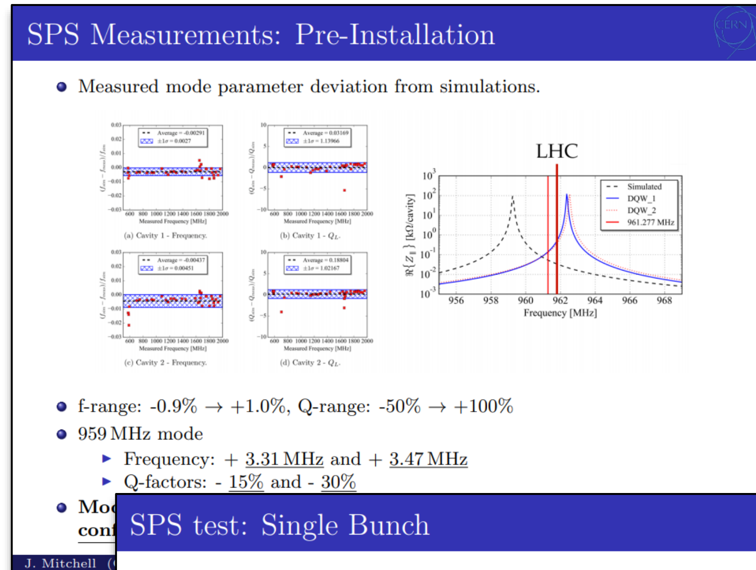
Radio Frequency Dipole (RFD)

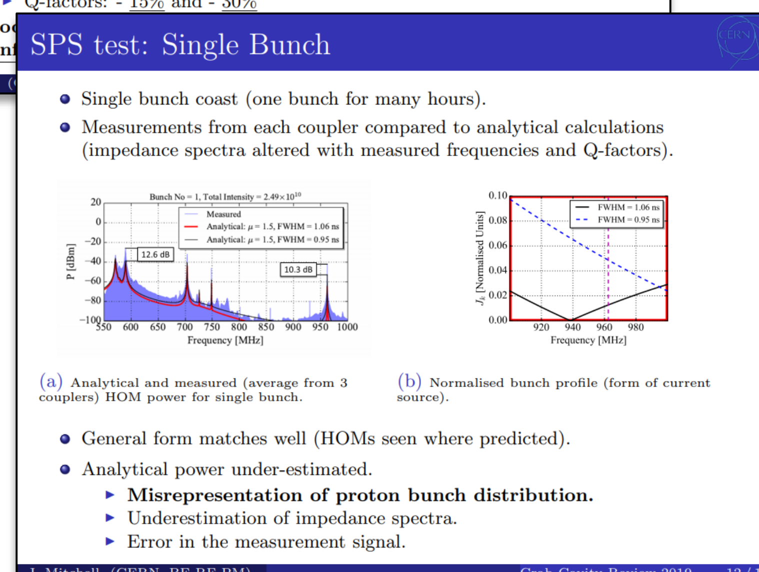
Crab cavity damping

- Dressed cavities tested without beam.
- Dressed DQW tested with beam!



S. Verdu-Andres





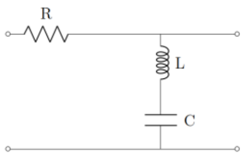
Topics

1. Dynamic heat loads (gasket heating)
2. Change of characteristic impedance (Z_0)

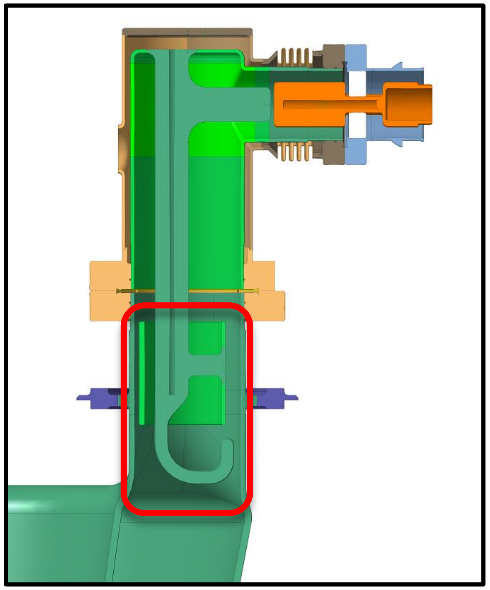
$$P = \int H^2 R_s \, dA$$

Dynamic Heat Loads

- Dynamic heat load on gaskets reduced by:



$$\omega_c = \frac{1}{\sqrt{LC}}$$

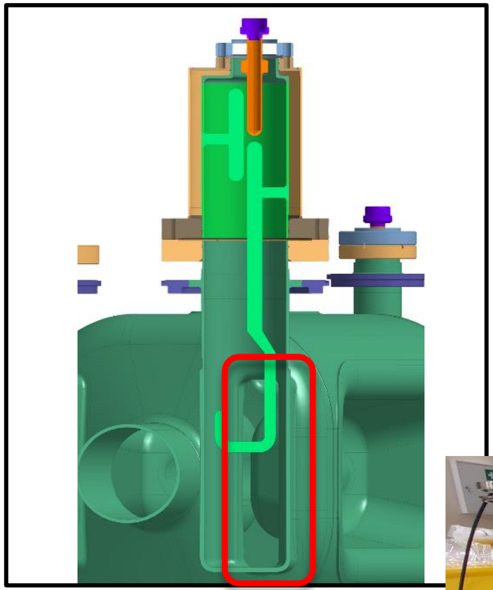


Rejection filter before the gasket.

→ complicated geometry

→ high fields on hook

→ broad notch (mW level heat-load)

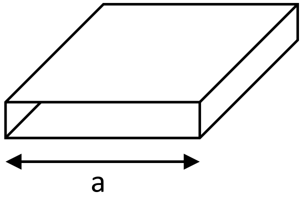


Waveguide with f_c > 400 MHz

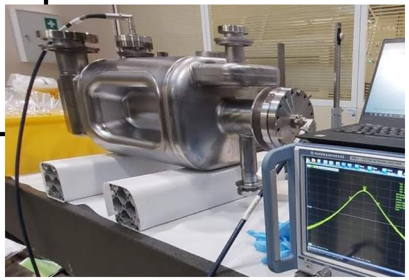
→ hard to machine and weld

→ higher nominal gasket heat-load

→ less sensitive to tolerances



$$\frac{c}{2f_{HOM1}} < a < \frac{c}{2f_0}$$



Could complex couplers and cavity shapes could be avoided with SC seals?

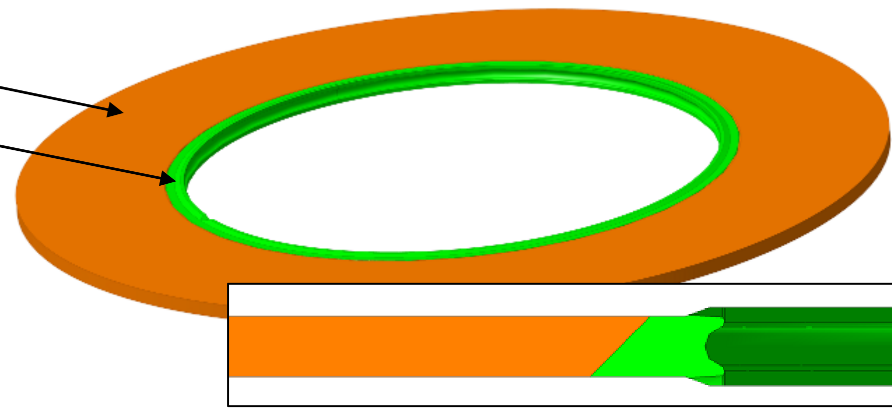
$$P = \int H^2 R_s \, dA$$

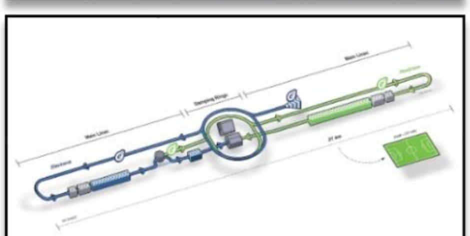
Dynamic Heat Loads

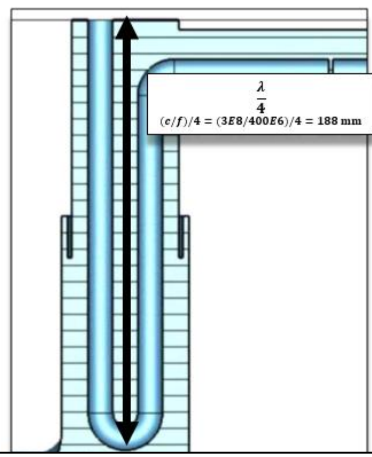
- Dynamic heat load on gaskets **could** be reduced by: Superconducting seals*.
- Resulting in more 'manufacturable' cavities and couplers.

Material	Rs @ 2 K [Ohms]
Copper	~ 1 e-3
Niobium	~ 20 e-9

We are trialing several options for tests!







On DQW the copper gasket heat-load is 2-20 W

Future high energy machines → mass production.

Do superconducting seals allow simplification of cavity and coupler geometries?

*Existing literature on the use of superconducting seals in back-up slides.

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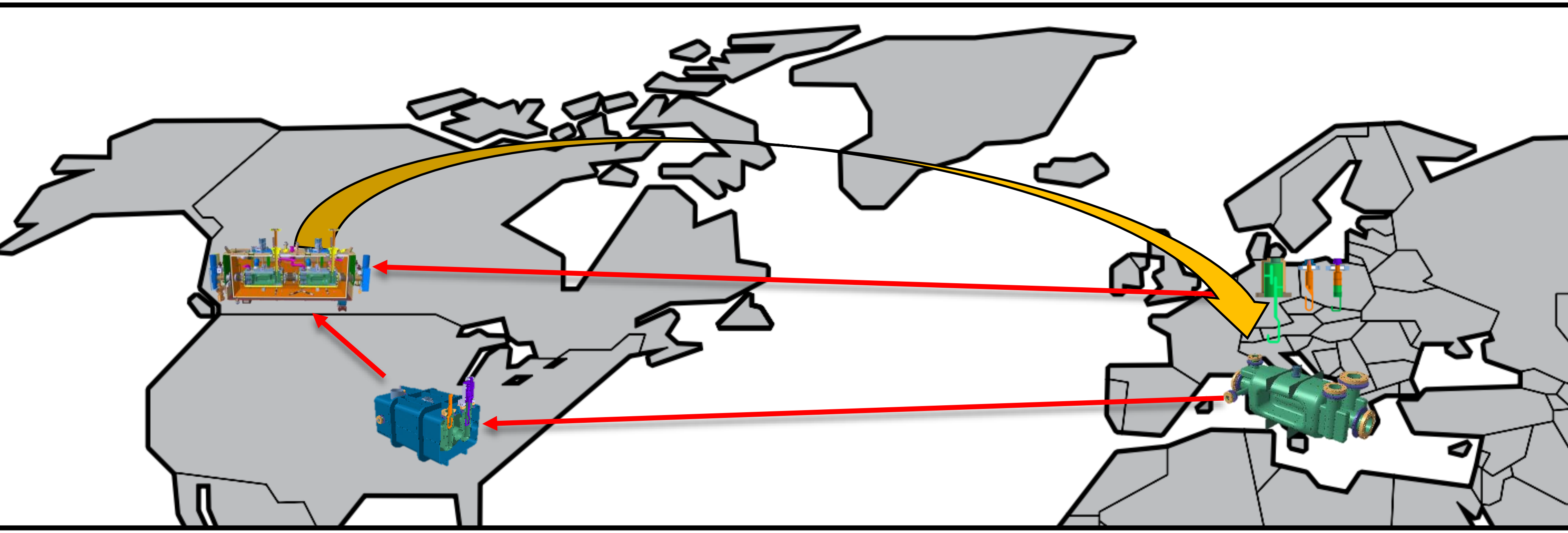
Changing Z_0: Manufacture and Transport



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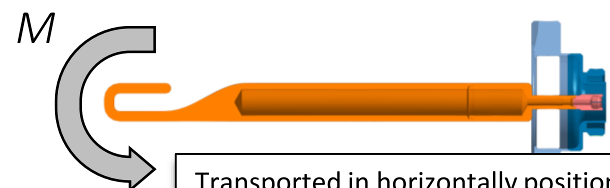
Changing Z_0: 50 Ω → 25 Ω

$$MI = \frac{\pi(OD^4 - ID^4)}{64}$$

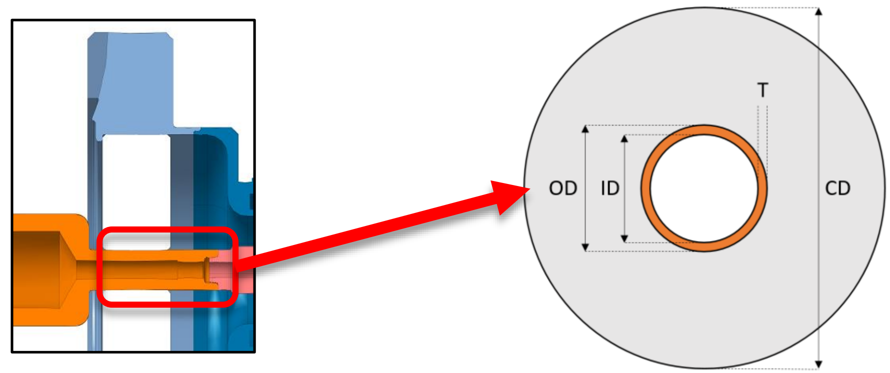
$$\text{Deflection} = \frac{L^3 F}{3E \cdot MI}$$

$$\text{Bending Stress} = \frac{FL}{MI/(0.5h)}$$

- … concerns over thin diameter in feedthrough.
- Changed to Z_0 = 25 Ω.



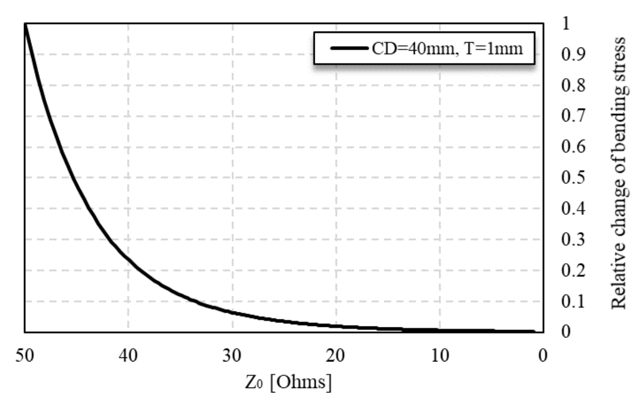
Transported in horizontally position.
Large moment on thin inner conductor!



Since $Z \propto log(OD/ID)$, diameter increases by factor of 3.7 if we move to 25 Ω.

Bending stress reduces by at least factor of 30. *

Z_0 [Ω]	ID [mm]
75	0.78
50	2.90
25	**10.77**



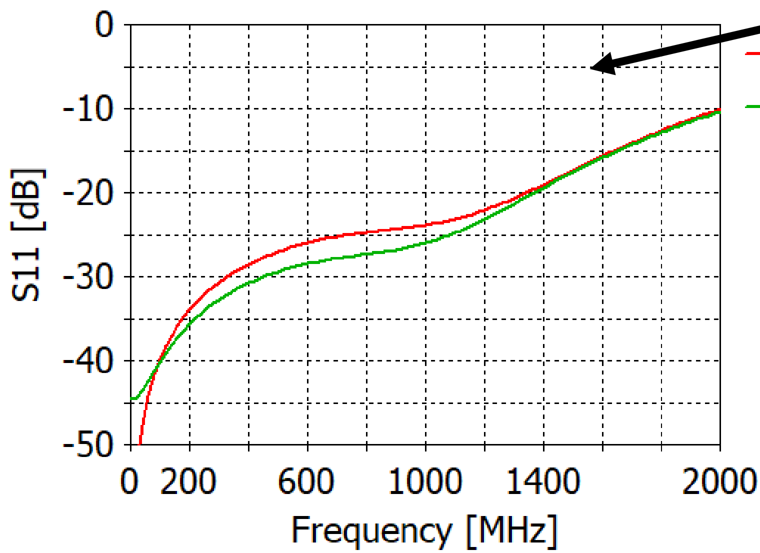
* Approximation without taking into account the boundary conditions of the ceramic.

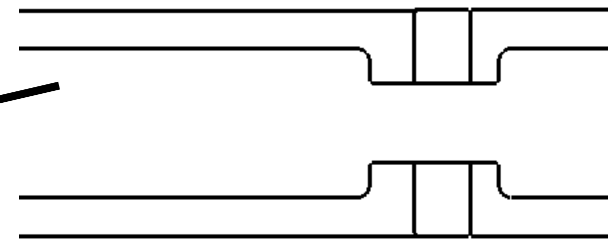
Shock test results and videos in back-up slides!

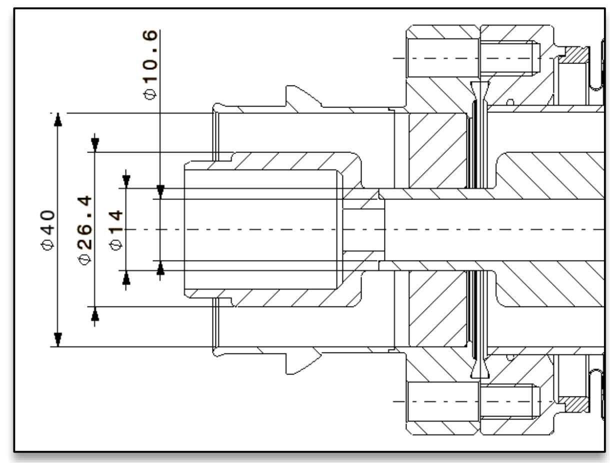
Changing Z_0: 50 Ω → 25 Ω

- Chose 25 Ω, because <u>25 Ω = 50 Ω || 50 Ω</u>
- Feedthroughs designed.

With the steps and clearances needed for manufacture.
<u>Inner diameter of 14 mm gave best broadband matching!</u>



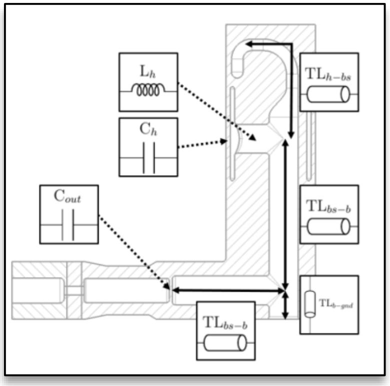


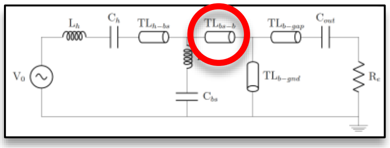


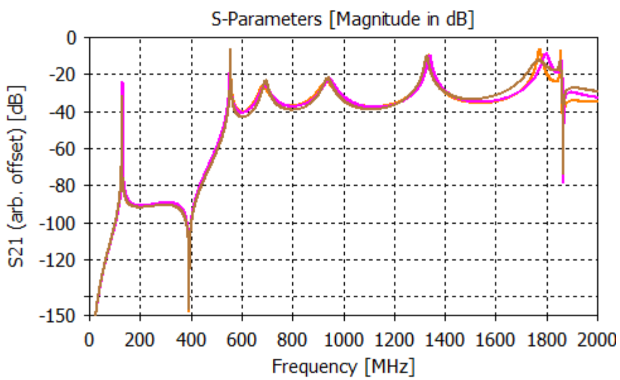
There is now a common 25 Ω feedthough validated with thermal shock and 'drop test'.

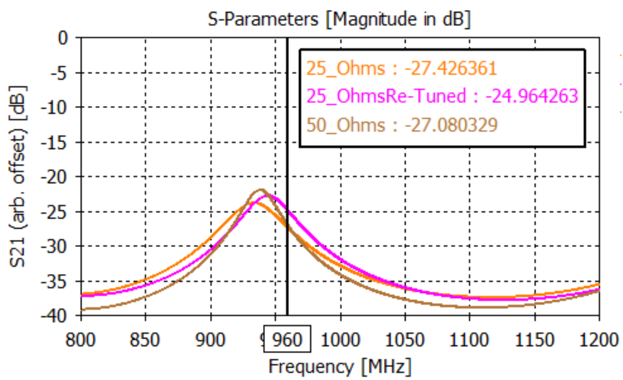
Changing Z_0: 50 Ω → 25 Ω

- DQW HOM coupler
  - Decrease in transmission at <u>high power mode frequency</u> (960 MHz).
  - Re-tuned - now impedance for this mode is the lowest it has been!



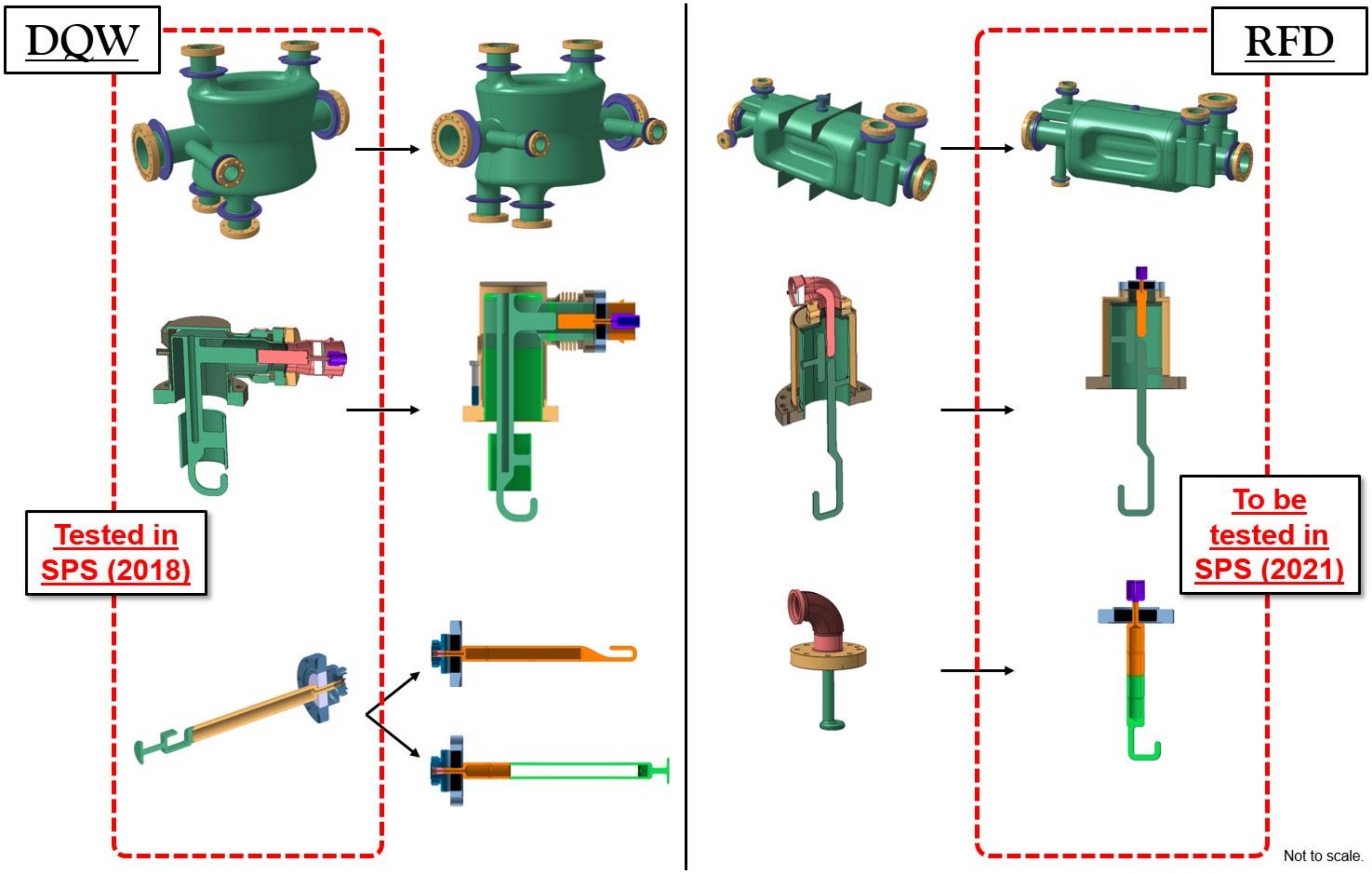






Design thresholds are met with 25 Ohm matching for both cavities!
Cavity impedances in back-up slides.

Changing Z_0: 50 Ω → 25 Ω



Changing Z_0: 50 Ω → 25 Ω

- Infrastructure and measurement challenges.
  - 25 ohm cables and loads are not standard: **Make cables of match in parallel?**
  - Using a 50 Ω VNA: **port re-normalization**, **de-embedding**, 50 Ω →25 Ω **adapters**.

matrix S, that is, with respect to the port impedance matrix

$$Z_0 = \begin{bmatrix} Z_{01} & 0 & \cdots & 0 \\ 0 & Z_{02} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & Z_{0n} \end{bmatrix}$$

we, first, transform S to an impedance matrix using (2.21)

$$Z = Z_0^{1/2} (U - S)^{-1} (U + S) Z_0^{1/2}$$

Next the impedance matrix is transformed into the S-parameter matrix S′

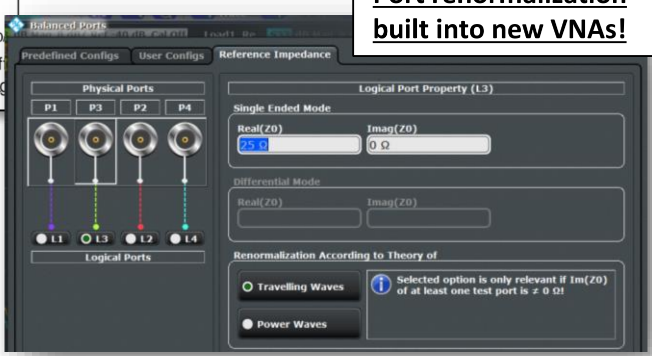
$$S' = Z_0'^{-1/2} (Z - Z_0') (Z + Z_0')^{-1} Z_0'^{1/2}$$

where now a reference impedance matrix of Z_0' is used

$$Z_0' = \begin{bmatrix} Z_{01}' & 0 & \cdots & 0 \\ 0 & Z_{02}' & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & Z_0' \end{bmatrix}$$

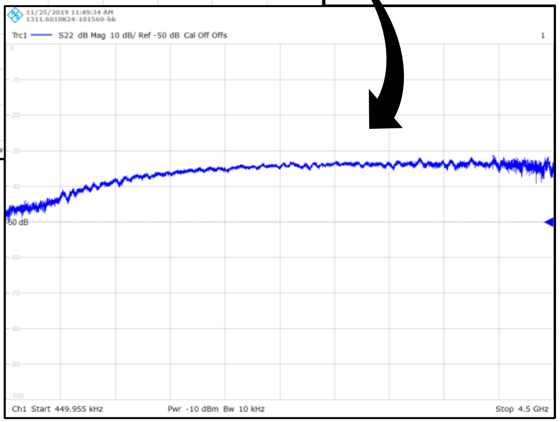
S′ is then with respect to Z'_0. Of

to 50 Ω in which case all the diag

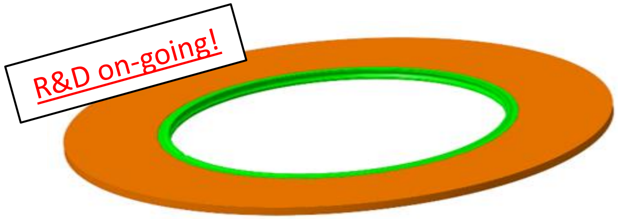


Port renormalization built into new VNAs!

WARNING:
Must de-embed adapter to 25 ohm section!

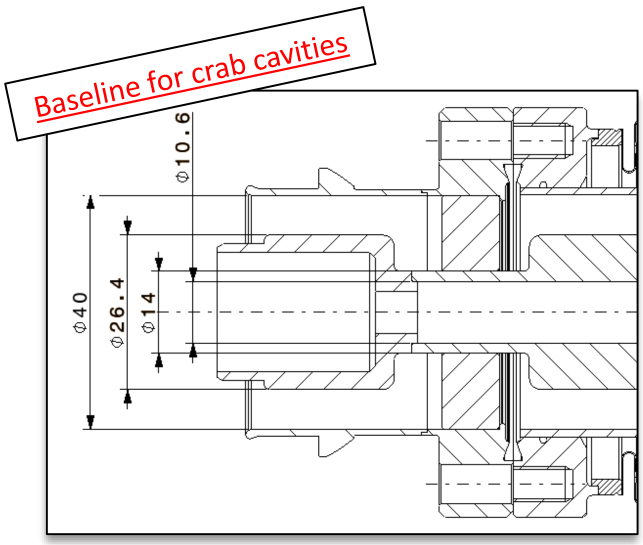


Conclusions and Discussion points



Dynamic heat loads

- We have reduced H-field.
- Could reduce Rs.
- <u>Could this lead to simpler structures?</u>
- <u>Is there a want for this in the accelerator community?</u>



Z0 = 25 Ω

- Inner conductor is too thin for transport.
- 25 Ohm infrastructure designed.
- Impedance thresholds met.
- Challenges: <u>infrastructure</u> and <u>measurements.</u>

Thank you for listening!

Thanks to BE-RF-PM and HL-LHC WP4 for the contribution and support.

Back-up slides

Fundamental mode RF parameters

Parameter	Unit	DQWCC	RFDCC
Frequency, f_0	MHz	400.44	400.75
Loaded Quality Factor, Q_l	-	—	—
$r/Q_\perp$ †	Ω/m	429	432
Deflecting Voltage, $V_\perp$	MV	3.4	3.4
E_{pk}	MV/m	38	35
B_{pk}	mT	73	60
Accelerating Voltage, $V_{\|\|}$	kV	13.9	1.9
Stored Energy	J	10.72	10.62
$\Re\{b_3\}$	mT/m^2	—	—

† Accelerator definition.

Ancillary	P (Coax) @ VT = 3.4 MV [W]		
DQW HOMC(1,2,3)	< 0.01	< 0.01	< 0.01
DQW HF-Damper	0.16		
DQW FA	1.02		
RFD H-HOMC	0.13		
RFD V-HOMC	0.42		
RFD FA	0.97		

Fundamental mode heat loads

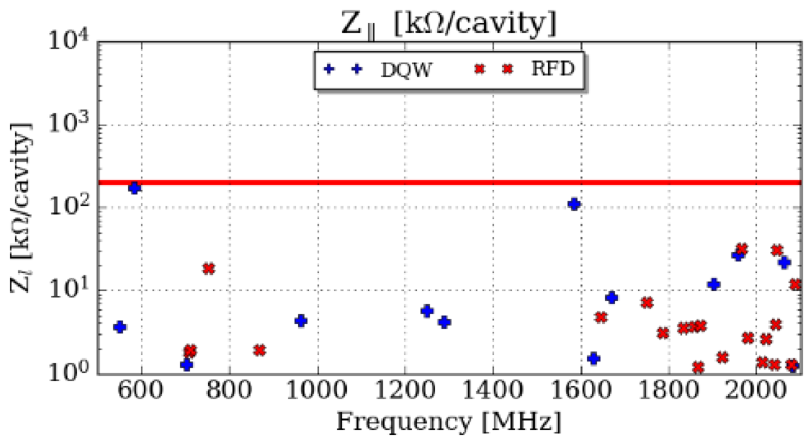
DQW

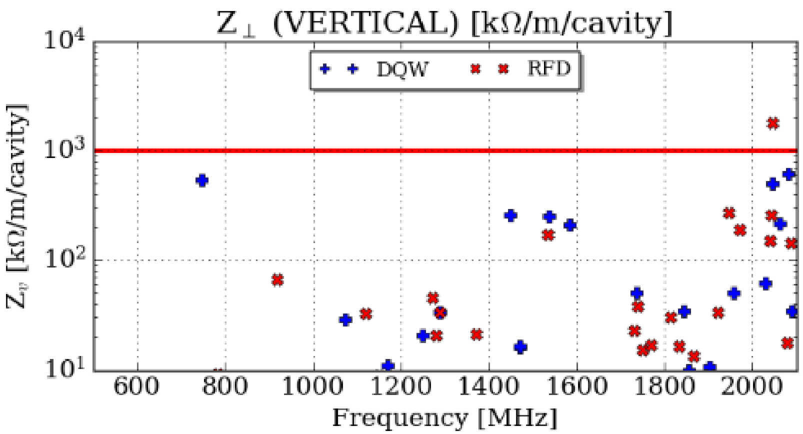
Component	Material	U = 1J			VT = 3.4 MV	VT = 5.0 MV
		Ploss [W]	Q0	Ploss [mW]	Ploss [W]	Ploss [W]
Cavity body	Nb	0.59	4.26E+09	592.34	6.35	13.73
HOMC1	Nb	0.00	1.35E+12	1.86	0.02	0.04
HOMC1 gasket	Cu	0.00	3.67E+12	0.69	0.01	0.02
HOMC2	Nb	0.00	1.11E+12	2.26	0.02	0.05
HOMC2 gasket	Cu	0.00	3.07E+12	0.82	0.01	0.02
HOMC3	Nb	0.00	1.12E+12	2.26	0.02	0.05
HOMC3 gasket	Cu	0.00	2.92E+12	0.86	0.01	0.02
FA	Cu	0.00	3.14E+12	0.80	0.01	0.02
FA gasket	Cu	0.00	6.18E+16	0.00	0.00	0.00
HF-Damper (Nb)	Nb	0.00	7.51E+14	0.00	0.00	0.00
HF-Damper (Cu)	Cu	0.00	6.94E+13	0.04	0.00	0.00
HF-Damper gasket	Cu	0.00	4.16E+17	0.00	0.00	0.00
Total [W]					**6.45**	**13.95**

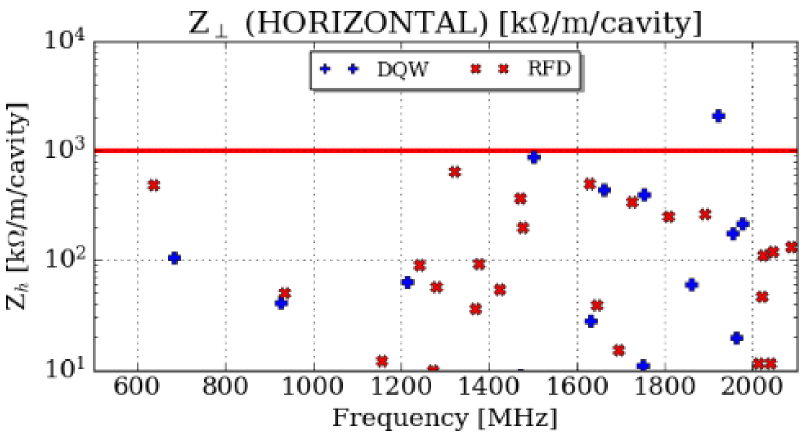
RFD

Component	Material	U = 1J			VT = 3.4 MV	VT = 5.0 MV
		Ploss [W]	Q0	Ploss [mW]	Ploss [W]	Ploss [W]
Cavity body	Nb	0.50	5.02E+09	501.07	5.32	11.52
H-HOMC (Nb)	Nb	0.00	2.48E+16	0.00	0.00	0.00
H-HOMC (Cu)	Cu	0.00	6.37E+14	0.00	0.00	0.00
H-HOMC gasket 1	Cu	0.02	1.53E+11	16.41	0.17	0.38
H-HOMC gasket 2	Cu	0.00	2.39E+15	0.00	0.00	0.00
V-HOMC (Nb)	Nb	0.00	1.04E+13	0.24	0.00	0.01
V-HOMC (Cu)	Cu	0.00	1.57E+12	1.61	0.02	0.04
V-HOM gasket	Cu	0.00	5.99E+16	0.00	0.00	0.00
Field Antenna	Cu	0.00	1.14E+13	0.22	0.00	0.01
Field Antenna gasket	Cu	0.00	2.69E+16	0.00	0.00	0.00
Total [W]					**5.52**	**11.94**

Impedance spectra







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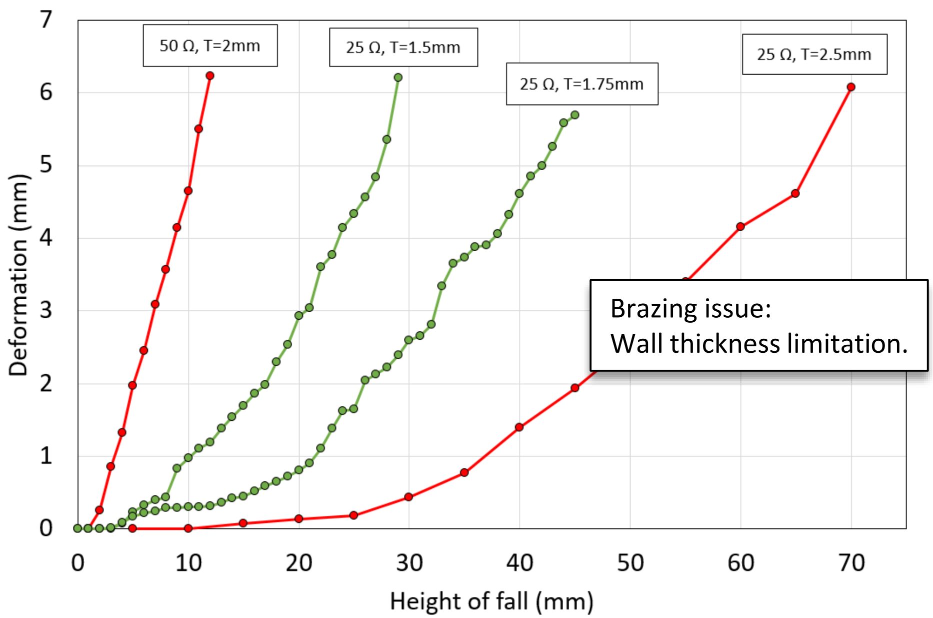
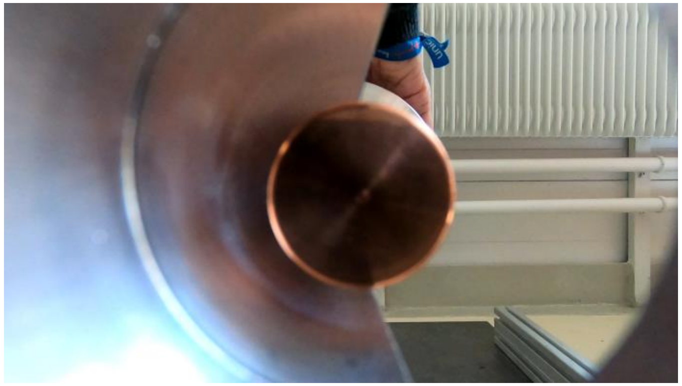
Changing Z_0: 50 Ω → 25 Ω

- ‘Shock tests’ on-going.





25 ohm feedthrough was shown to be more resistant to a shock!

High Power HOMs

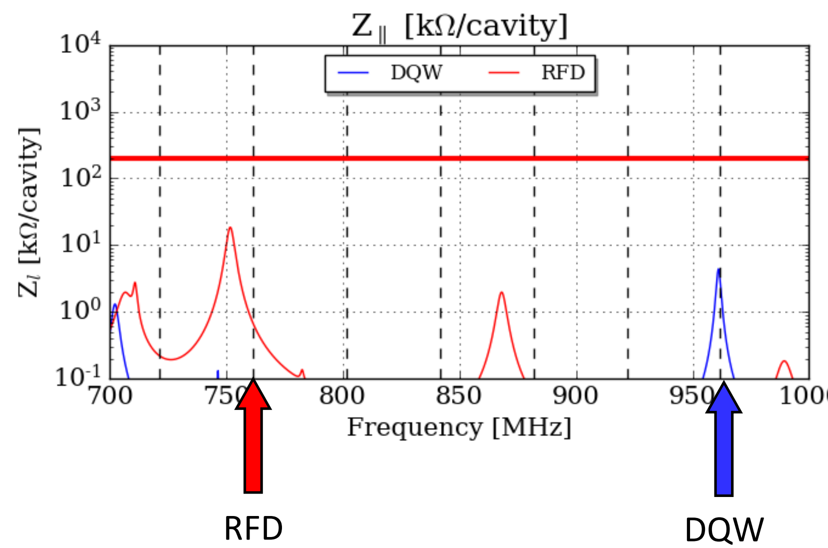
- Coaxial line power is becoming comparable to FPC power.

Using HL-LHC beam parameters:

	$P_{worst\text{-}case}$ ($P_{average}$) [kW]	
	Gaussian bunch	Binomial bunch
DQW	1.0 (0.2)	0.5 (0.1)
RFD	7.4 (0.8)	5.9 (0.7)

HOM power from 10,000 stochastic simulations.

Parameters: bunch length, bunch form coefficient, mode frequencies and mode Q-factors.



Worst case power at these frequencies.

- Infrastructure for HOM couplers is becoming <u>larger</u> and <u>more difficult to assemble/replace</u>.
- What will be the best damping method for future machines?

ImageGen