Review of Expected Crab Cavity Heat Loads Due to Impedance

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Some HOMs close to a multiple of the bunch spacing frequency might cause massive heat load

Example: DQW design (update of 10.2016)

Shunt impedance (Ω)	Quality factor	HOM Frequency (Hz)
9.34E+07	2.17E+10	4E+08
2.13E+04	1.60E+03	5.64E+08
0.005098	1.05E+03	5.69E+08
5.401713	1.04E+03	5.69E+08
1.15E+05	2.63E+03	5.86E+08
0.206092	6.71E+03	6.81E+08
417.1959	2.34E+03	6.82E+08
6.313443	1.06E+03	6.83E+08
0.205469	5.37E+00	8.53E+08
0.662133	5.39E+00	8.54E+08
3.30E-07	7.95E-01	8.6E+08
0.002906	6.09E+02	9.28E+08
1.14E+04	1.17E+03	9.6E+08
2209.216	2.62E+05	1.04E+09
55.08195	7.83E+02	1.07E+09

High R + close to a beam harmonic

Why is this not an issue in normal RF cavities?

The main mode is transverse, not longitudinal

- The HOMs are lower in frequency

The crab cavities sit in the places with high β

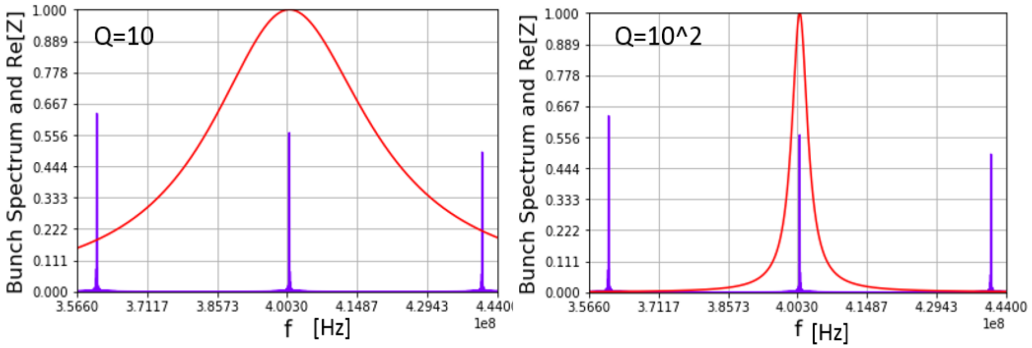
- Low Q of the HOMs is needed to ensure transverse stability

See also:

- N. Biancacci et al., Effect of tail cut and tail population on octupole stability threshold in the HL-LHC, HSC Meeting, 05.10.15
- E. Metral, Impedance update (other components than Crab Cavities), Joint LARP CM26/Hi-Lumi Meeting, SLAC, 19.05.16
- E. Metral et al., CC: Impedance status, International Review of the Crab Cavity Performance for Hi-Lumi, CERN, 05.04.17

Simulation procedure

1. Take the actual beam spectrum



Courtesy F. Giordano

2. Sum the contributions of all the HOMs

$$P = 2(q_e N_b M f_0)^2 Z_{\parallel,\mathrm{eff}}$$

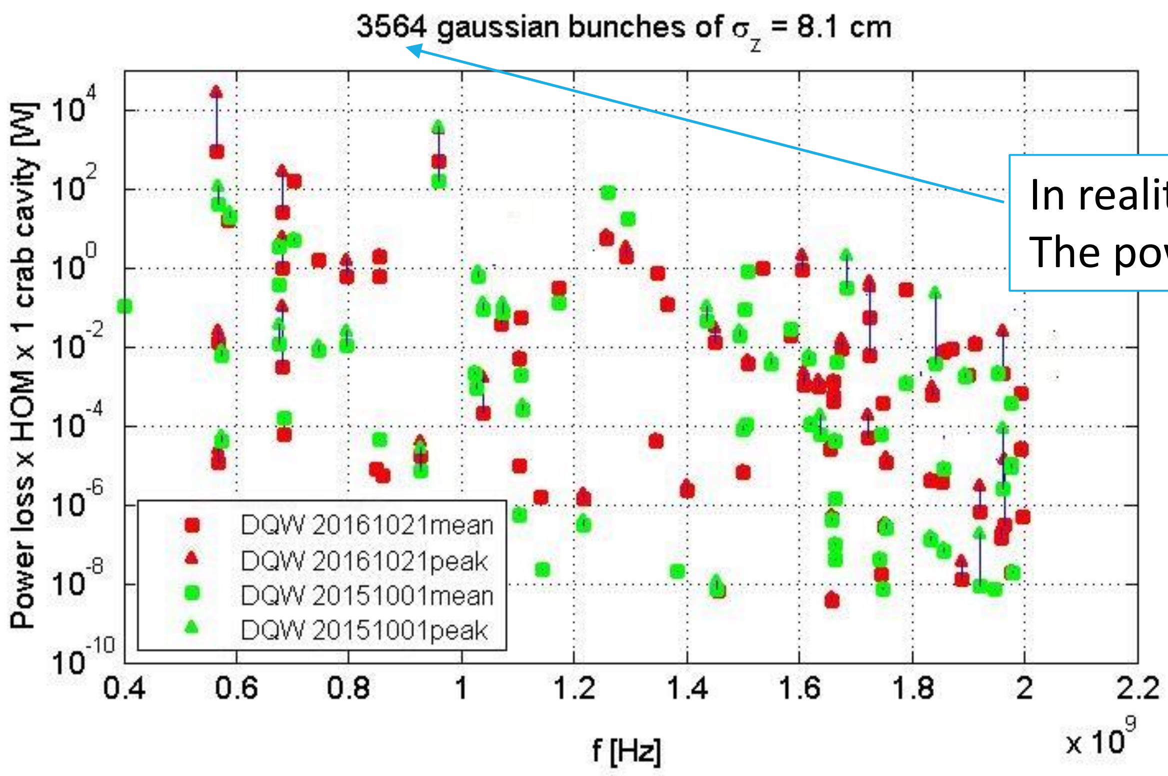
p per bunch   No. bunches

3. N. Biancacci's code:
   1. Adding an extra ±3 MHz spread to the HOM frequencies to account for manufacturing uncertainties
   2. Equidistant Gaussian bunches

4. B. Salvant's code:
   1. Actual filling pattern
   2. Gaussian or $\cos^2$ distribution

Double Quarter Wave: Total heat load has increased

2.2x10^{11} ppb
25 ns spacing



In reality, not all the buckets are filled
The power loss will be lower

The sidebands of the beam spectrum significantly affect the power loss. It is quadratic with the number of bunches only if only the main line contributes

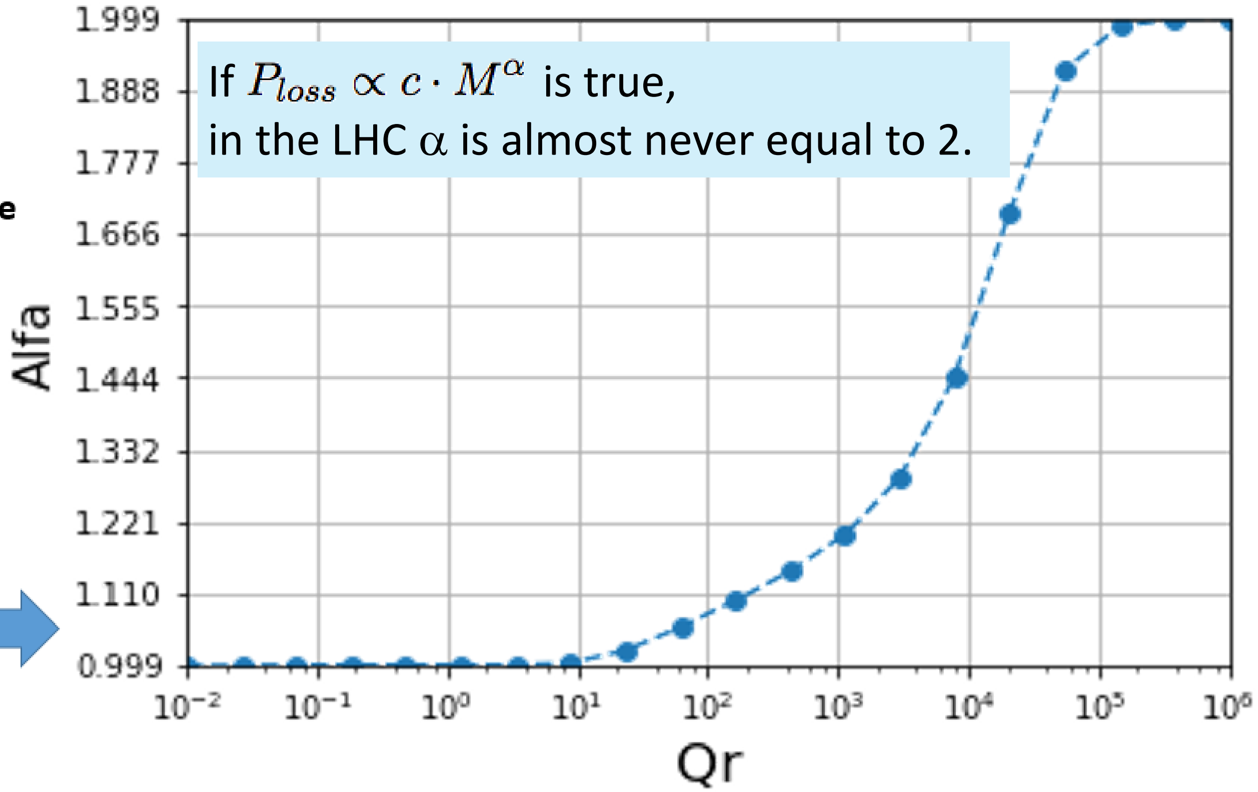
From [1] we know that:

- Broad Band impedance -> The sum can be replaced with an integral → $P_{loss} \propto M$
- Very narrow band impedance (**1 term in the sum**) → $P_{loss} \propto M^2$

In the meeting of the 10/04/2017 we have assumed that in the middle case we have:

$$P_{loss} \propto c \cdot M^{\alpha}$$

And for an ideal Gaussian filling scheme we have obtained

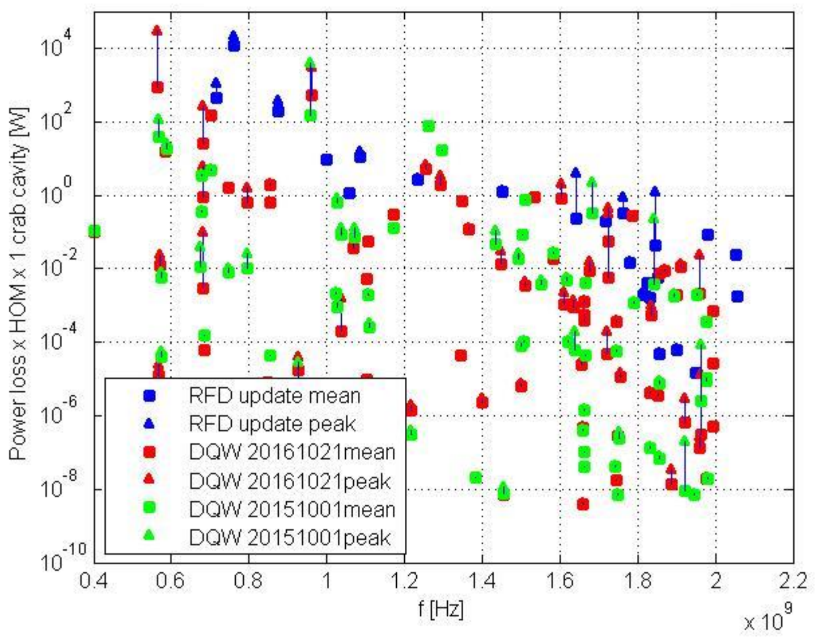


F. Giordano, B. Salvant, Update on power loss for resonator impedance with various filling schemes, APB HSC Meeting, 08.05.17

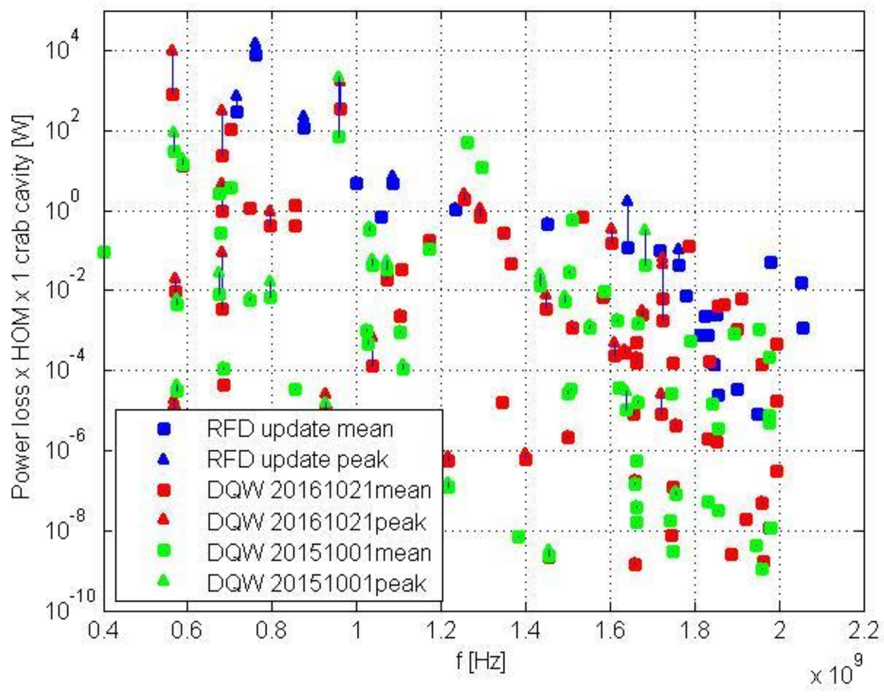
Going to 9 cm rms bunch length decreases the peak power loss

The effect is more prominent at 1 GHz and higher

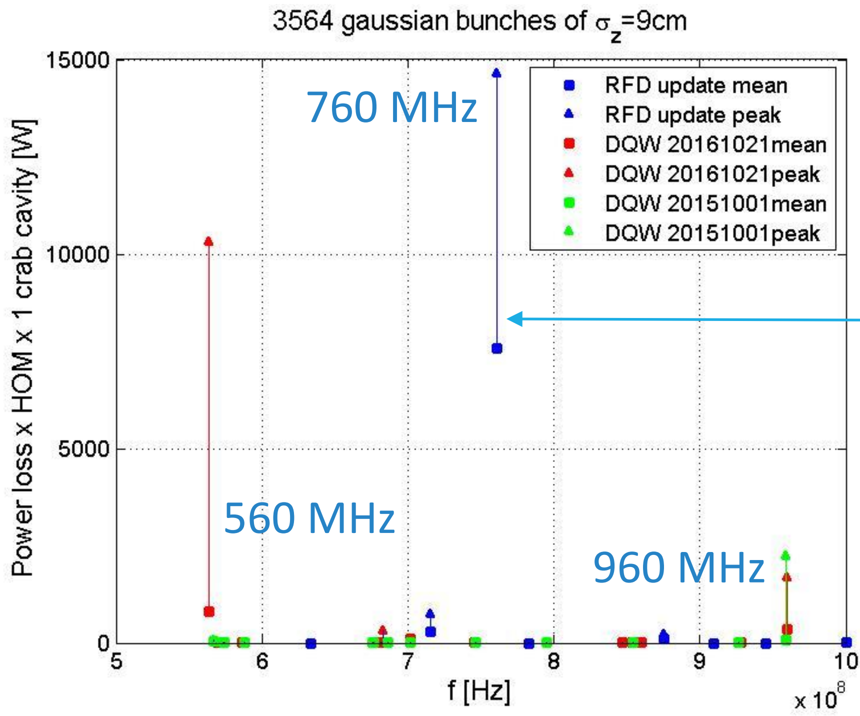
8.1 cm rms bunch length



9.0 cm rms bunch length



The most dangerous modes



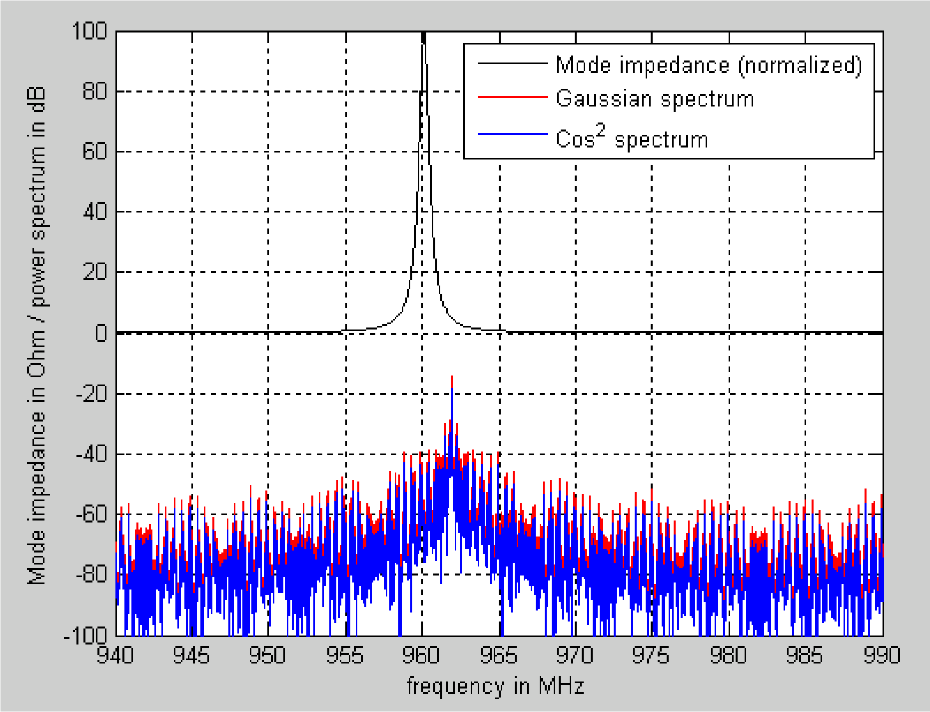
The recipe of high loss:

- High R 28 kΩ
- Low Q 300
- Close f 761 MHz

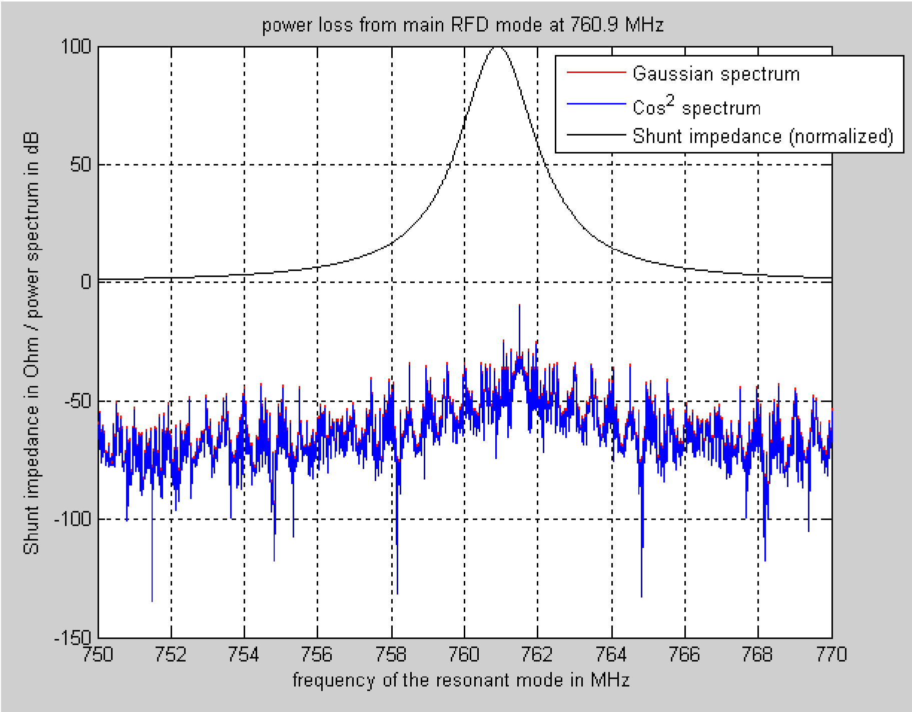
We need the HOMs to have low Q to ensure the transverse stability

Intersection of the mode line with the peak in beam spectrum leads to kW-scale power losses

DQW



RFD



For a more realistic $\cos^2$ spectrum the losses are lower. Up to a factor of 2 for a 1 GHz mode in DQW

Need to look at all potentially dangerous modes

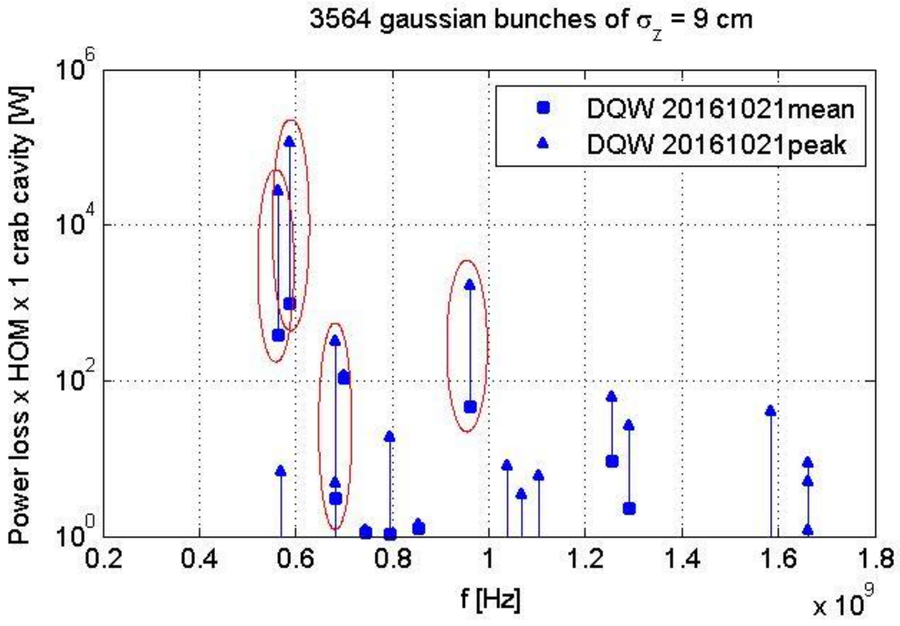
The modes may shift significantly during the tuning

- As far as 50 MHz
- No way of controlling the individual frequencies

To be safe, one might need to take into account all potentially dangerous modes

- Not only the ones that are close to beam harmonics at the moment

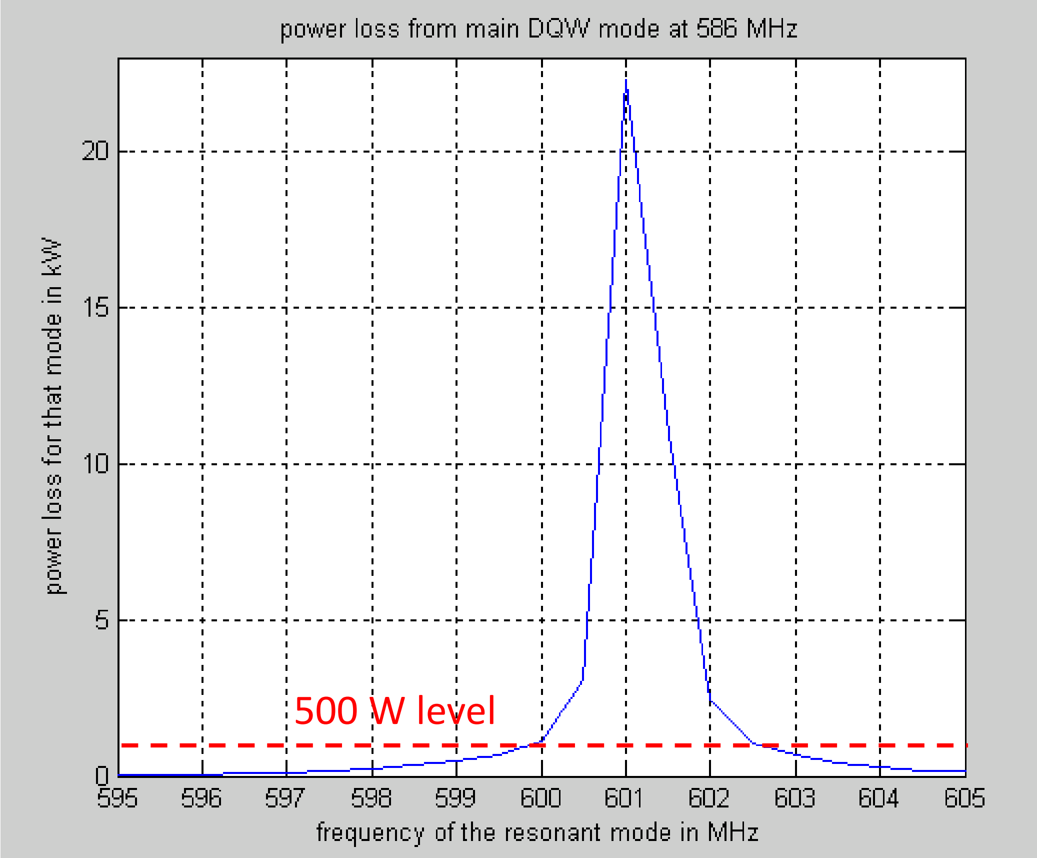
Adding a ±25 MHz spread to HOM frequencies



The modes with peak power loss > 100 W are highlighted

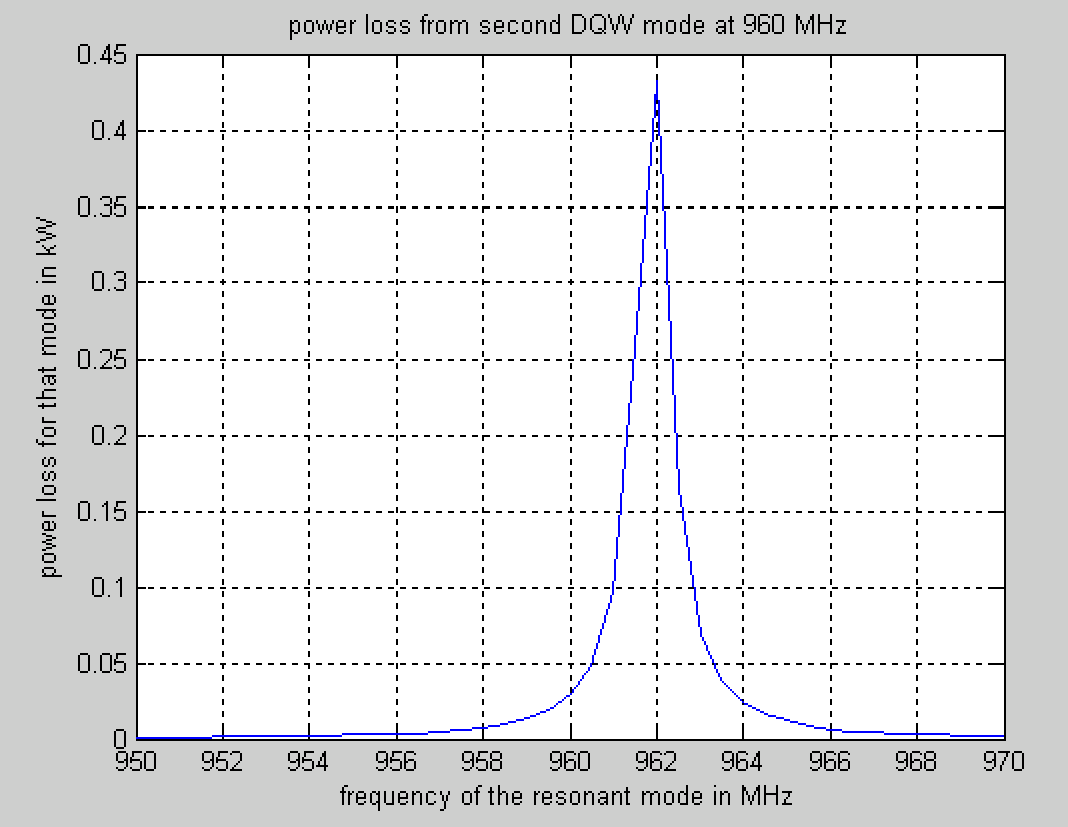
DQW: Stay at least 2 MHz away from the critical HOMs

Intensity	$2.2x10^{11}$ ppb
No. bunches	2748
Bunch distribution	Cos^2
Mode frequencies	586 MHz
Q-factor	2600
Shunt imp.	115 kΩ



DQW: Stay at least 2 MHz away from the critical HOMs

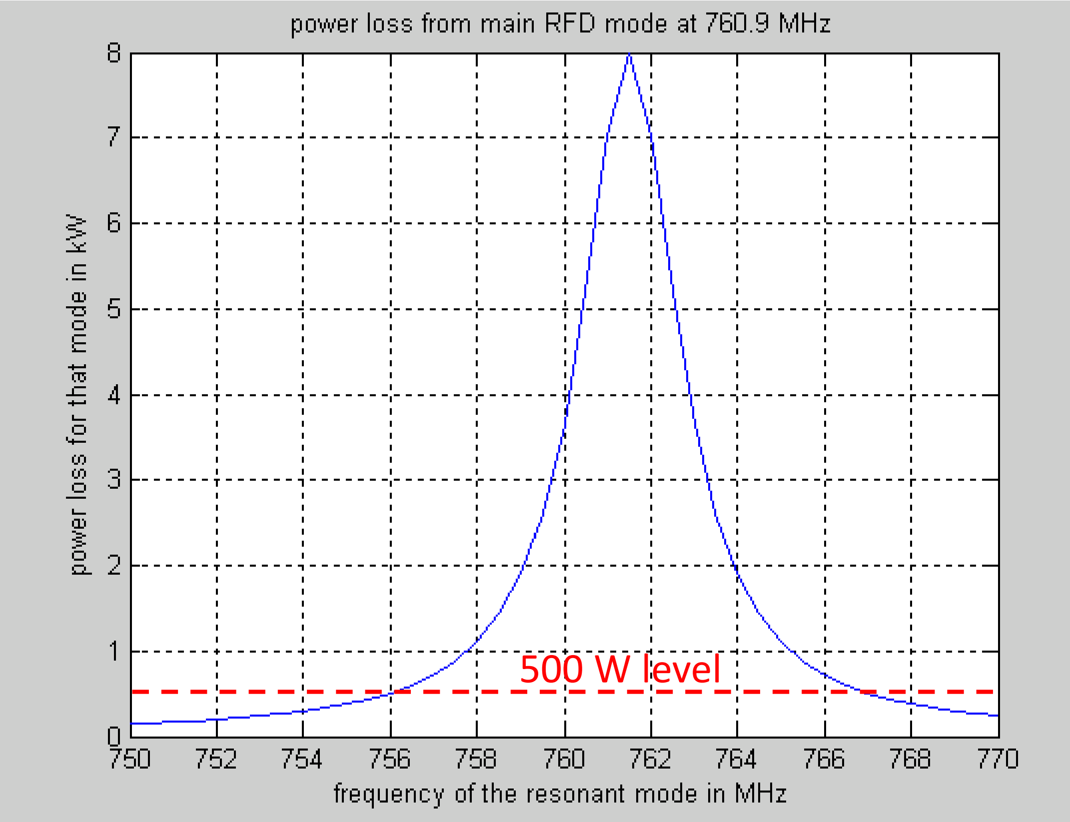
Intensity	**2.2×10^{11} ppb**
No. bunches	2748
Bunch distribution	Cos^2
Mode frequencies	960 MHz
Q-factor	1100
Shunt imp.	11 kΩ



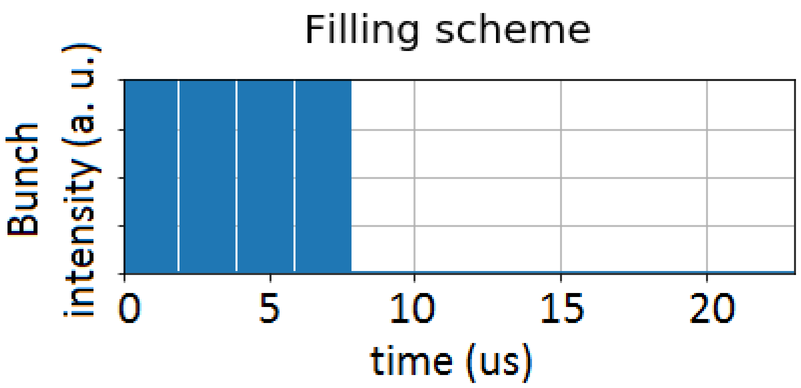
Can significantly reduce the losses from the 2nd potentially dangerous mode

RFD: Stay at least 5 MHz away from the critical HOM

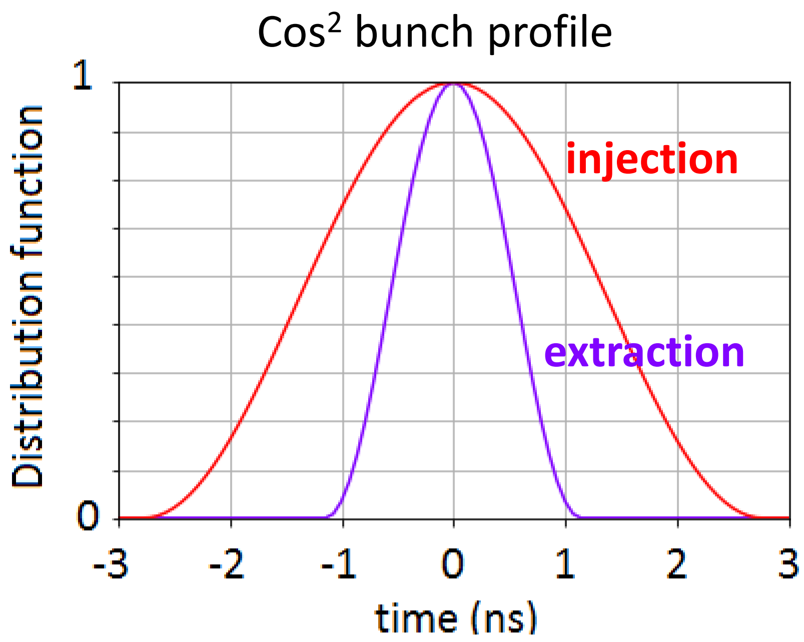
Intensity	2.2×10^{11} ppb
No. bunches	2748
Bunch distribution	Cos^2
Mode frequency	760 MHz
Q-factor	290
Shunt imp.	28.7 kΩ



What can be measured at SPS?

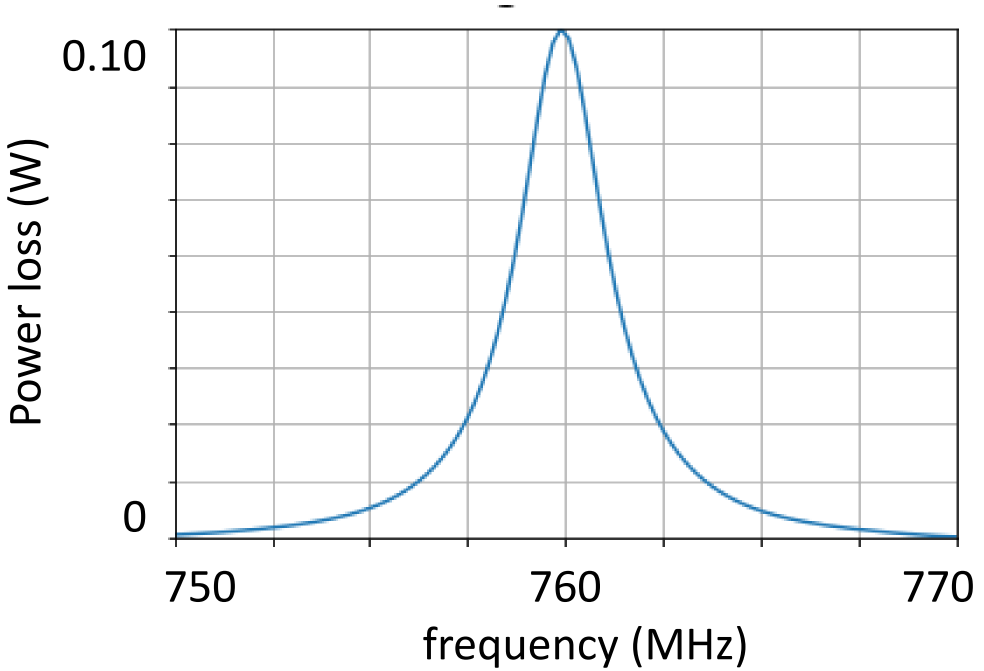


Intensity	1.35×10^{11} ppb
No. bunches	288
Bunch length, extraction	1.65 ns
Bunch length, injection	4.0 ns

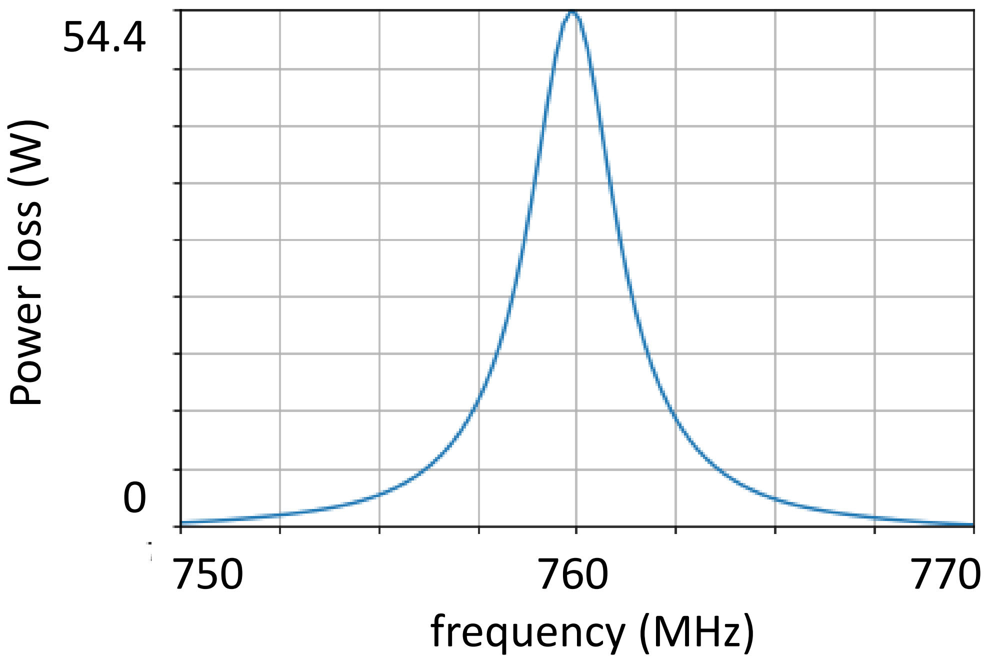


RFD: up to 50 W at extraction

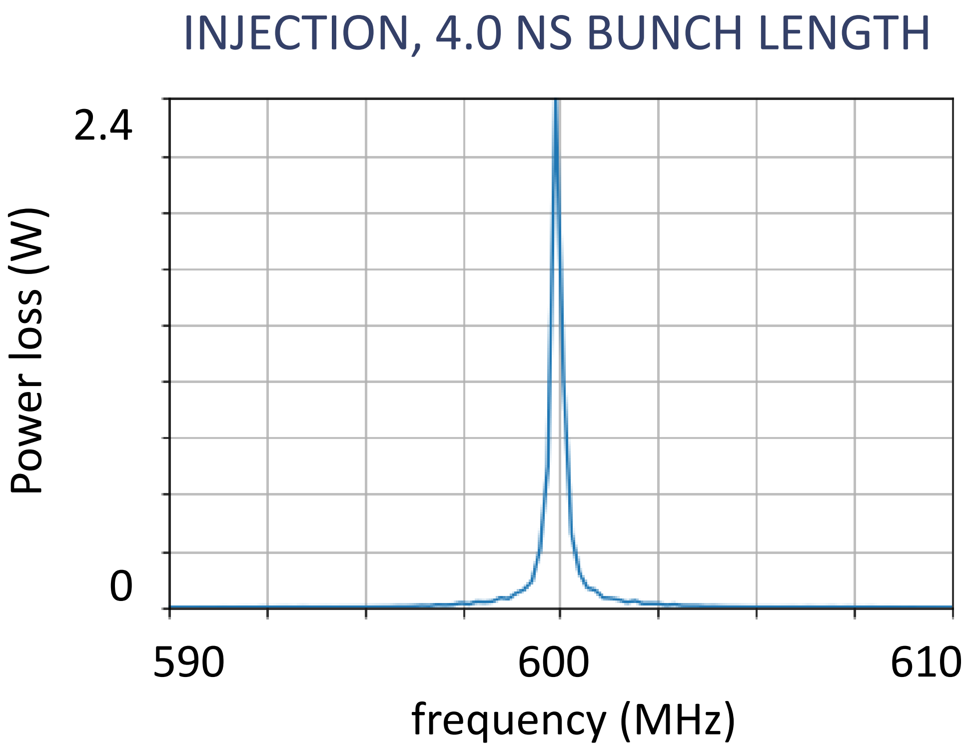
INJECTION, 4.0 NS BUNCH LENGTH

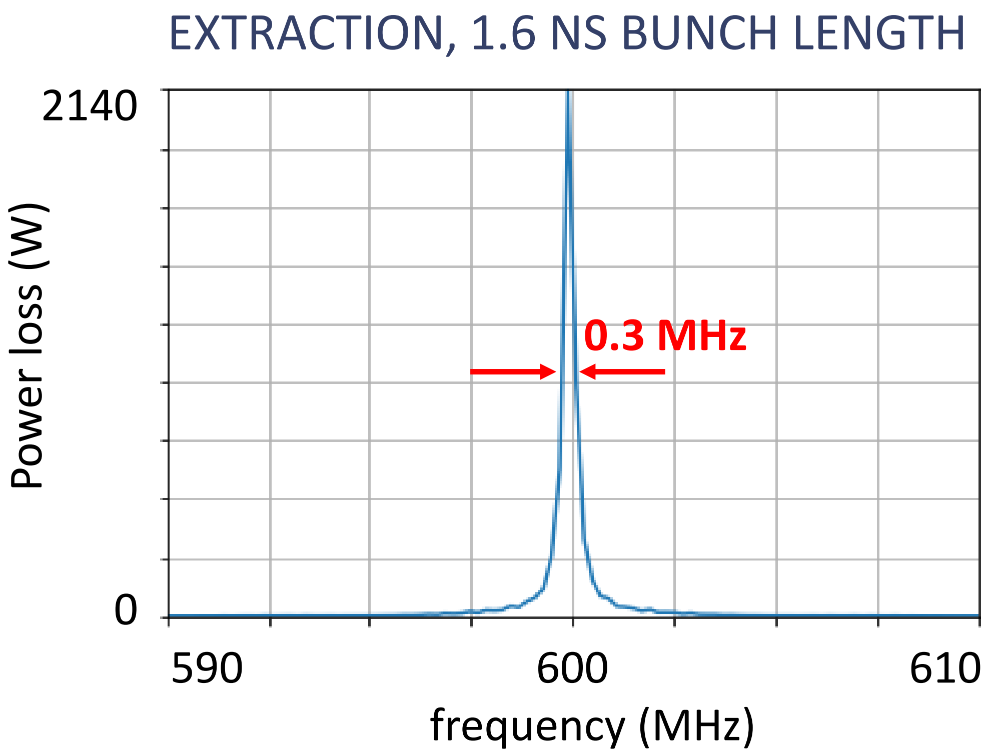


EXTRACTION, 1.6 NS BUNCH LENGTH



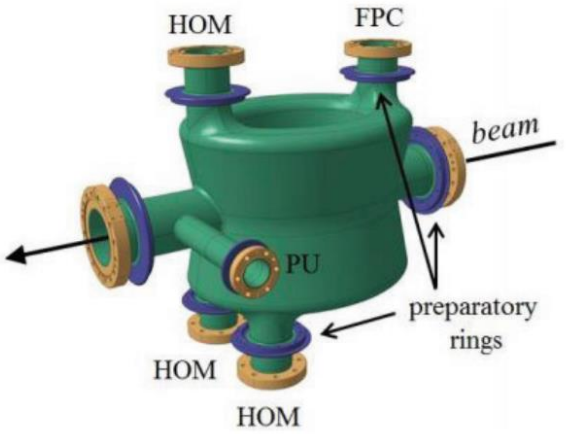
DQW: up to 2 kW, very narrow peak





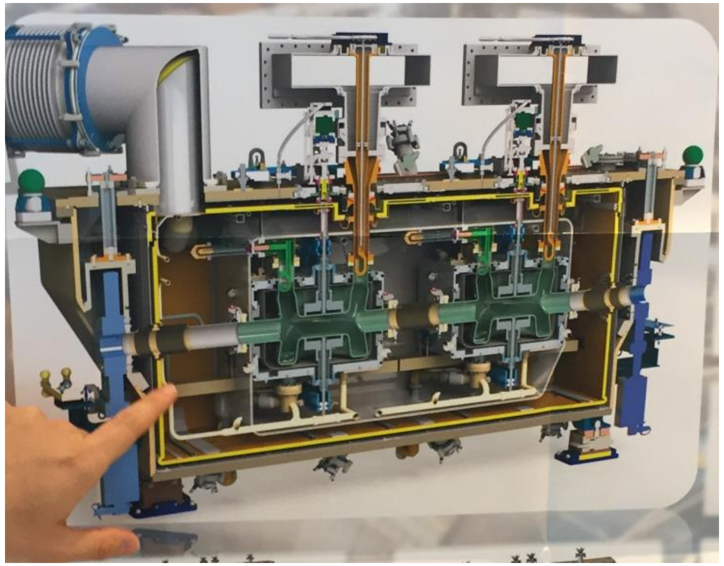
DQW: HOM damping system is designed to take up to 1 kW

DQW has several HOM couples



J. A. Mitchel et al., IPAC’16, Busan, Korea

The coaxial line can transport up to 1 kW of HOM power load out of the cavity



Thermal breakdown might be an issue

A dedicated breakdown test is foreseen

Summary

If a high-impedance HOM is close to a beam spectrum line, it may lead to a high power loss

- kW-scale losses!

HOM lines can be quite broad (low-Q), making it challenging to avoid

Would like to have at least 2-5 MHz from the harmonics of 40.08 MHz to keep the beam induced heating below 500 W

- How feasible it actually is?

As measurement in SPS might reveal some information

- Substantial power loss
- Tens of Watts can be achieved at extraction
- May be hard to tune on certain lines