SPS-DQW HOM Measurements

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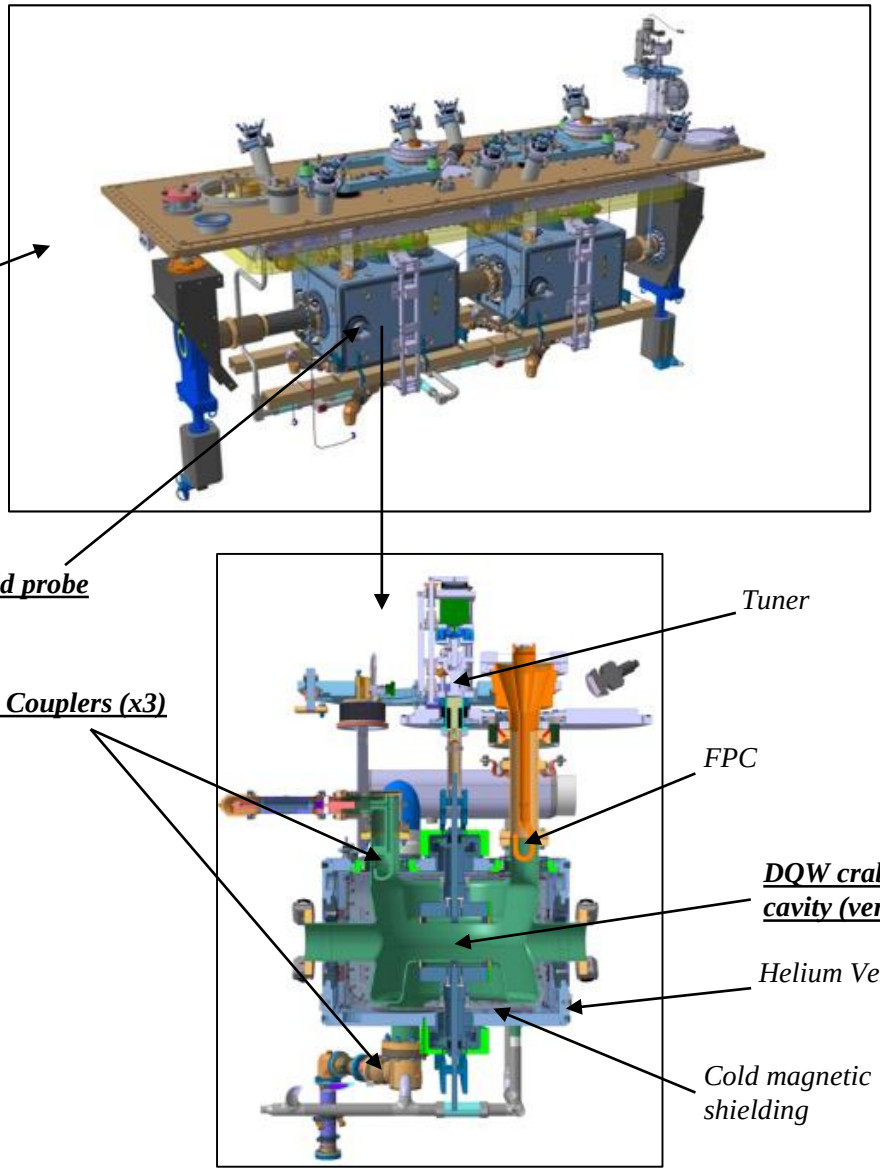
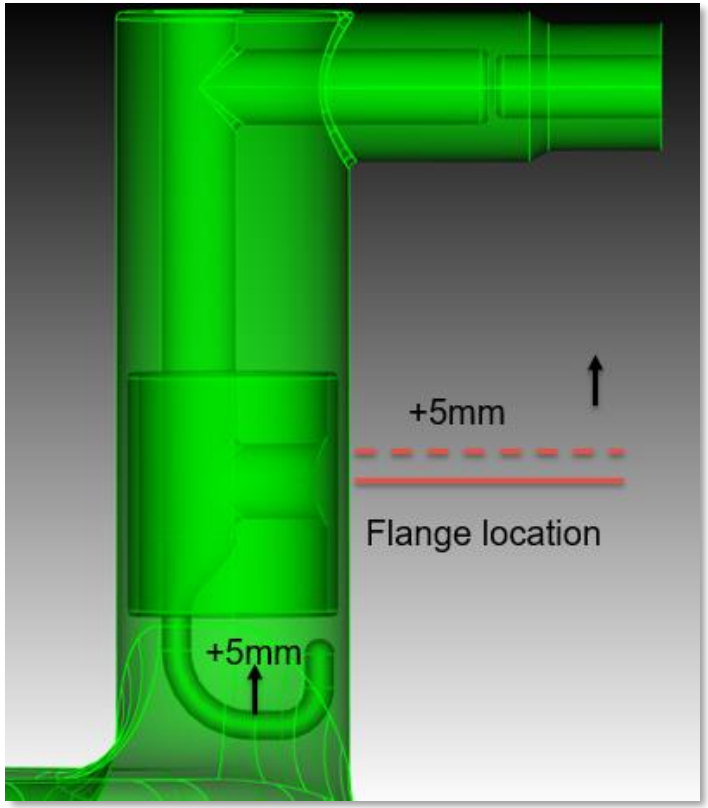
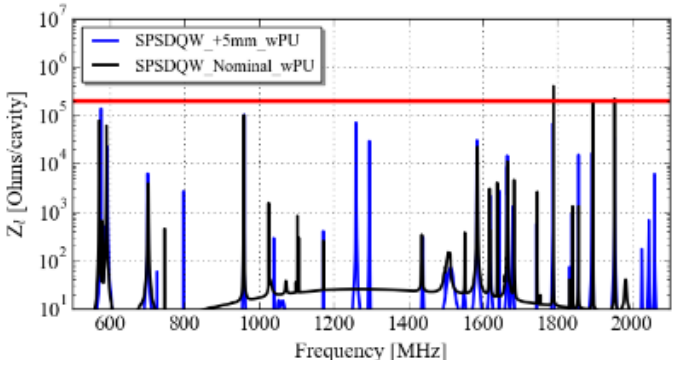
SPS Crab Test Stand

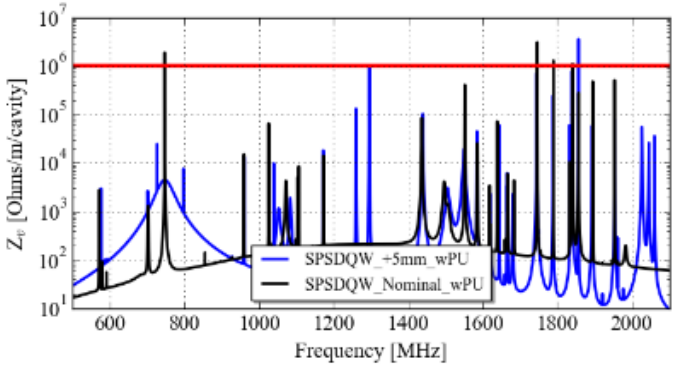


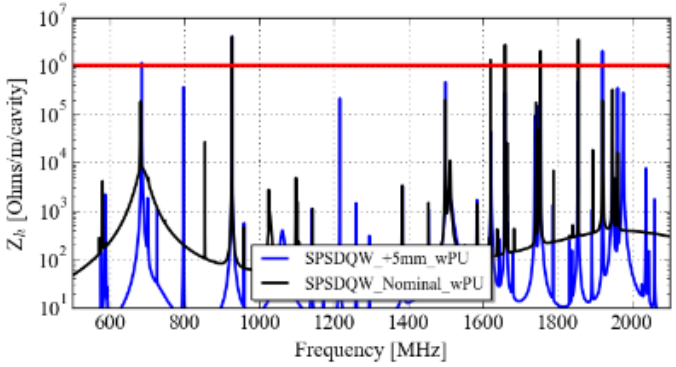
Non-conformity

- All HOM coupler ports are **+ 5 mm** compared to design.
- Reduces coupling to majority of HOMs
- Does not present impedance issue for SPS test.



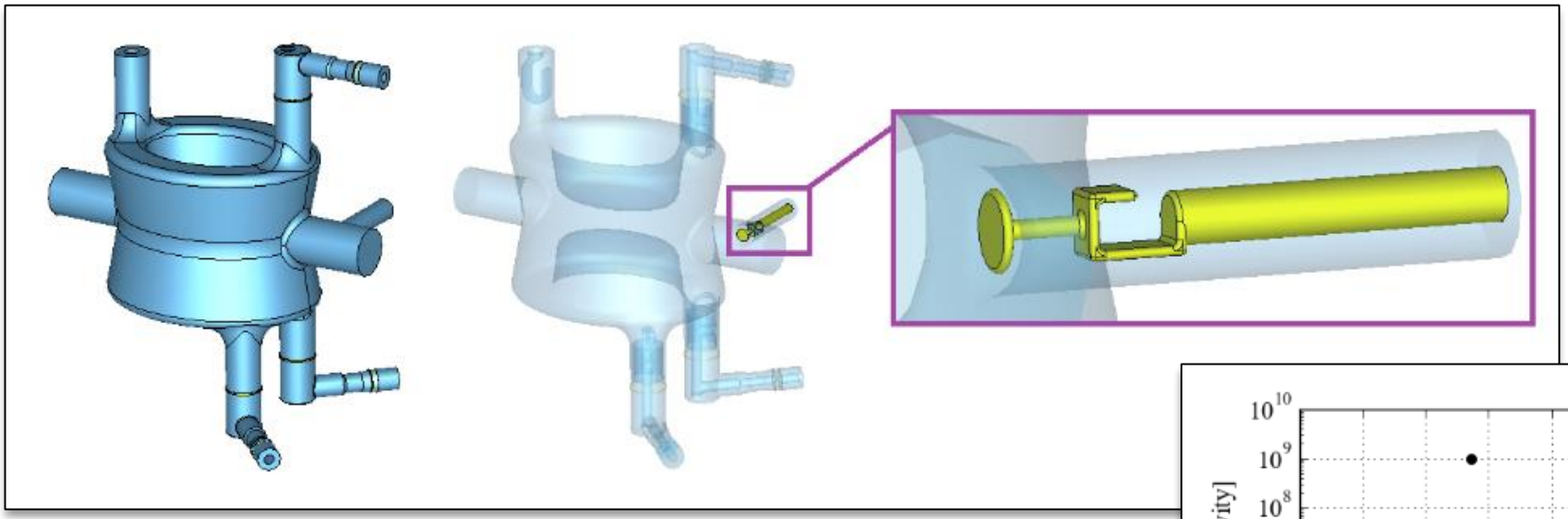


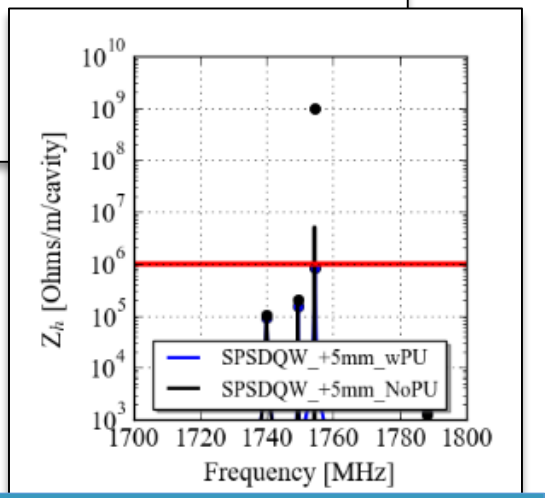




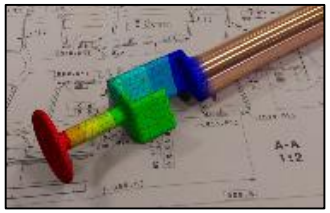
Field Probe as Fourth HOM coupler

- The pick-up is designed extract 1 W at the fundamental mode frequency → $\mathbf{Q_e = 1.6 \times 10^{10}}$.
- It is also a HOM coupler for the 1.5 GHz and 1.75 GHz modes
  - → cannot couple to this mode with HOM couplers.



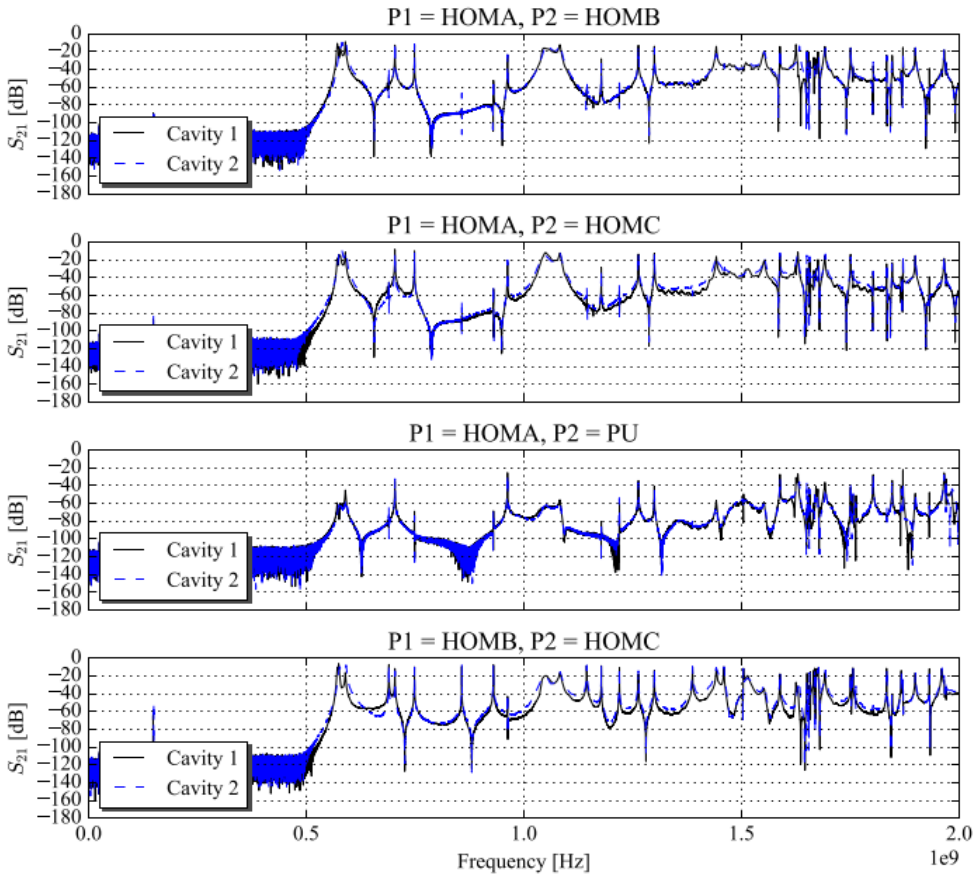


- The PU is made from Nb and Cu to avoid heating.



Mode Measurements

- Transmission measurements using VNA in cryomodule cold test in M7 buncker.



Mode Measurements

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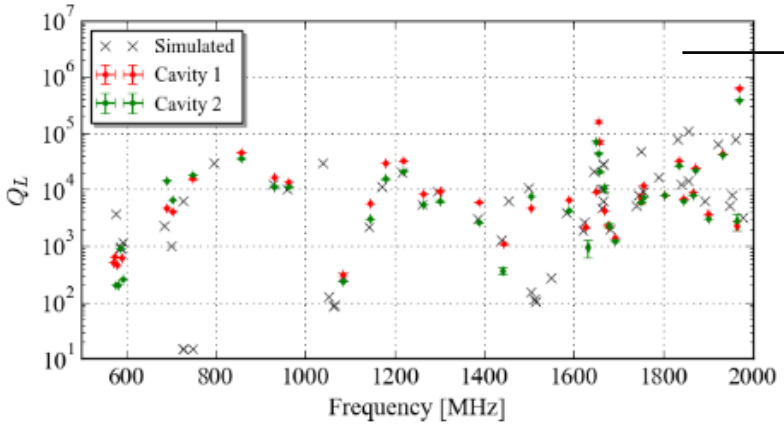
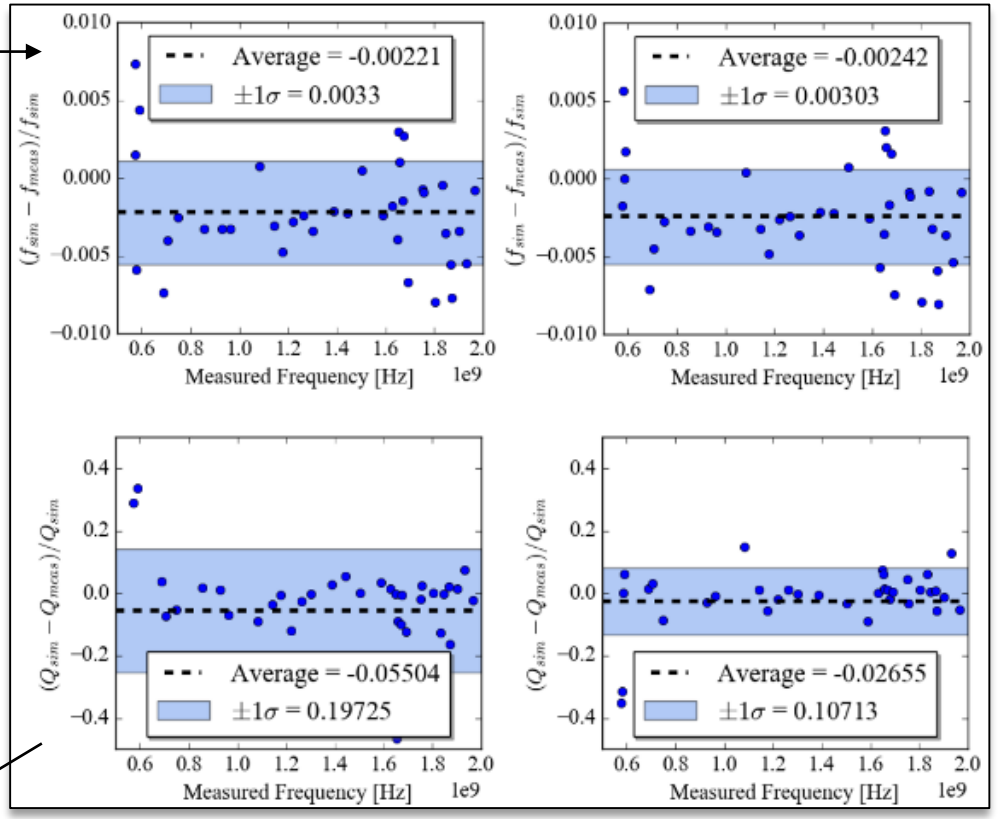




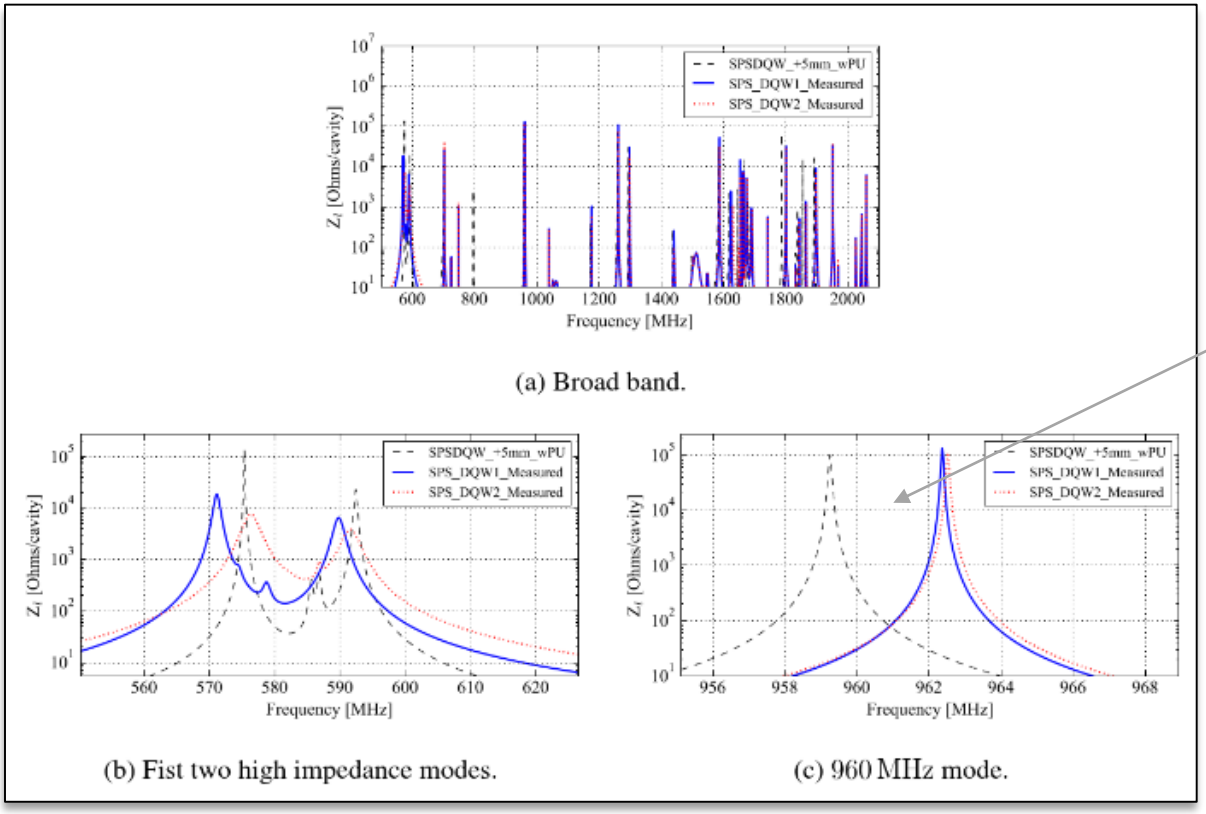
Deviations are hence:

$$\frac{\Delta f}{f} = 0.003$$

$$\frac{\Delta Q_e}{Q_e} = 0.2$$

Modified Impedance Spectra

- Impedance spectra:
  - Frequencies and Q_e values are known for a large number of modes.
  - **<u>Simulated spectra altered for both cavities.</u>**
  - Note, remembering to use the +5 mm simulation results!

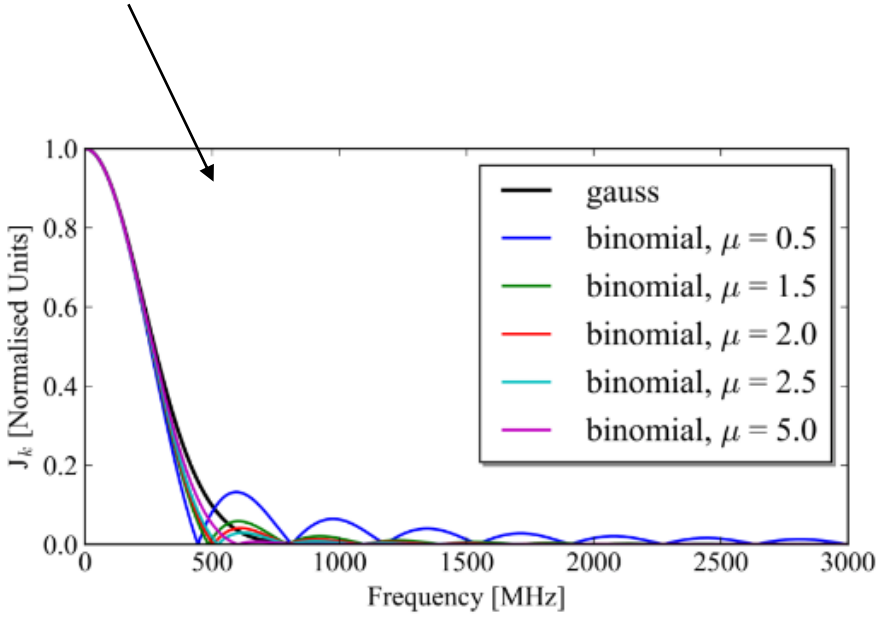


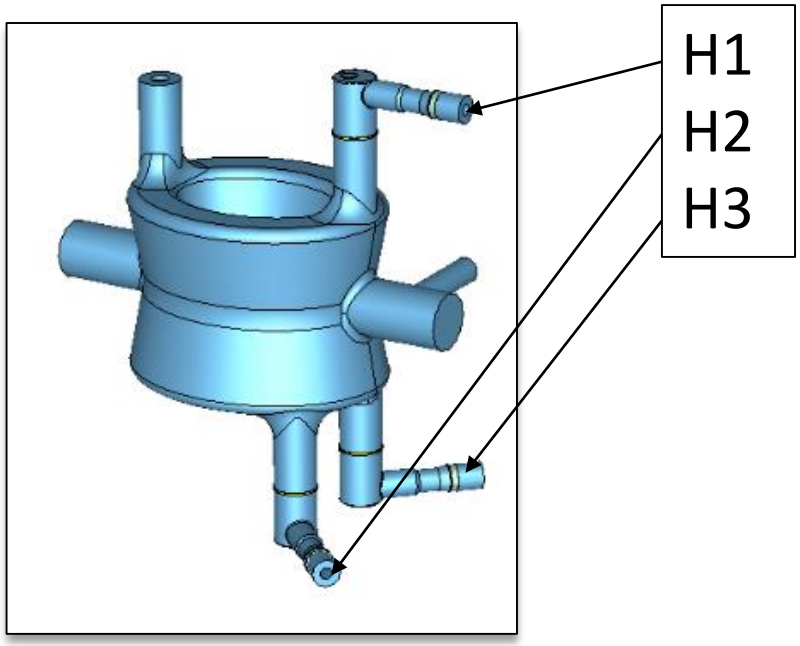
- For both cavities the 960 MHz mode has increased in frequency.
- From BELOW to ABOVE the harmonic!
- This shows it is feasible for the mode to be excited by the 24th harmonic at 25 ns bunch spacing.

Measurements with Beam

- **Measurement aims:**
  1. **Validate we can predict HOM power accurately.**
  2. **Validate we have not 'missed modes' in simulation.**
  3. **Validate power increases with intensity (and bunch number) as expected.**

- Analytic calculations:
- A binomial distribution was used to represent the bunch profile.

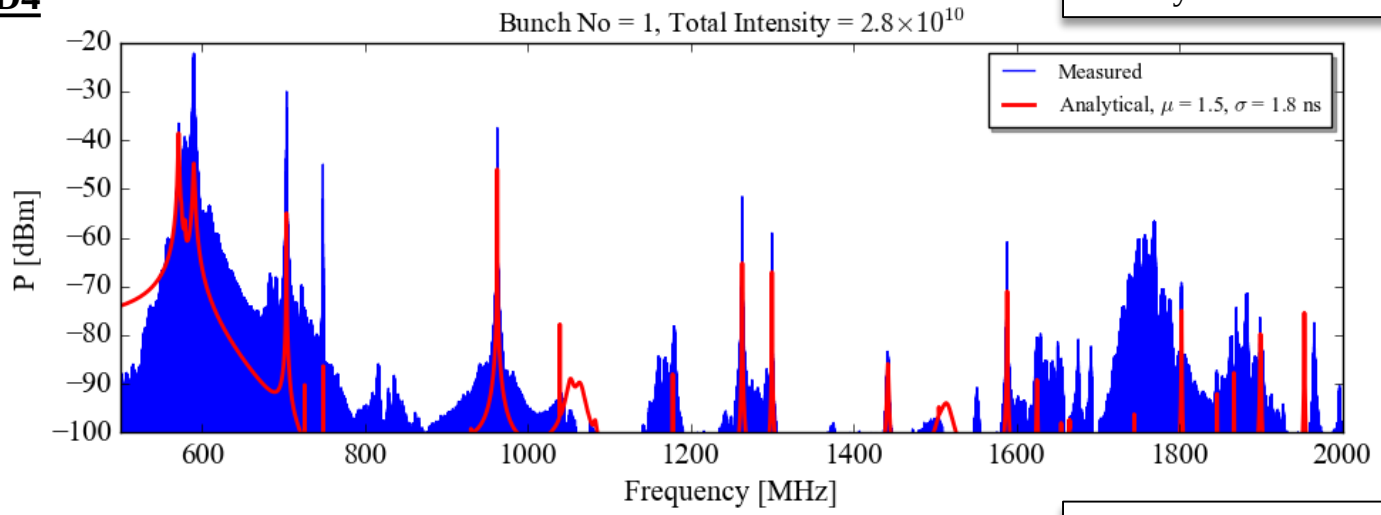




Meas. with Beam: *Single Bunch*

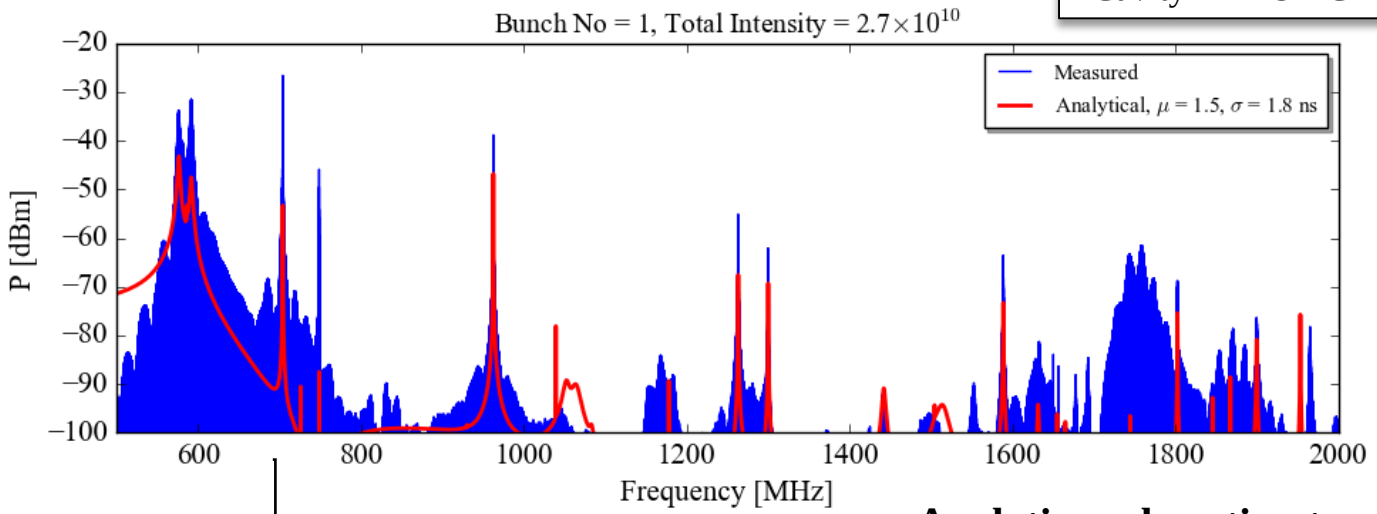
27/08/2018: MD4

Cavity 1 - HOMC1



Predicted is total power, not accounting for intra-coupler power flux.

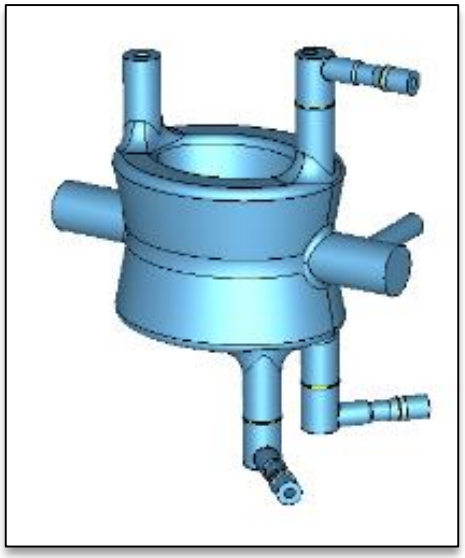
Cavity 2 - HOMC1



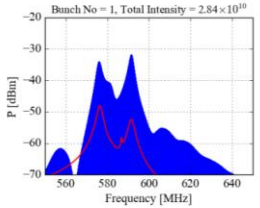
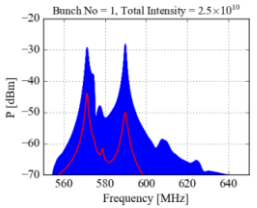
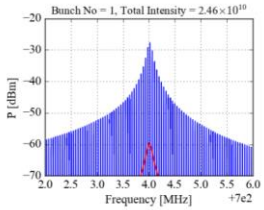
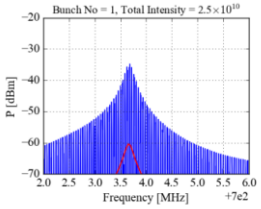
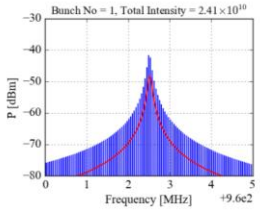
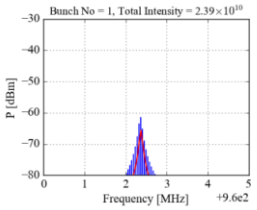
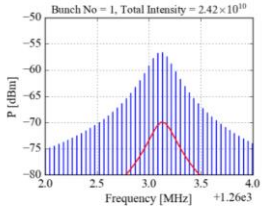
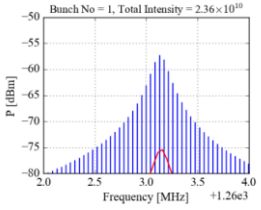
- **Analytic underestimates**
- **Unforeseen power at 1.8 GHz**

Meas. with Beam: *Single Bunch*

27/08/2018: MD4

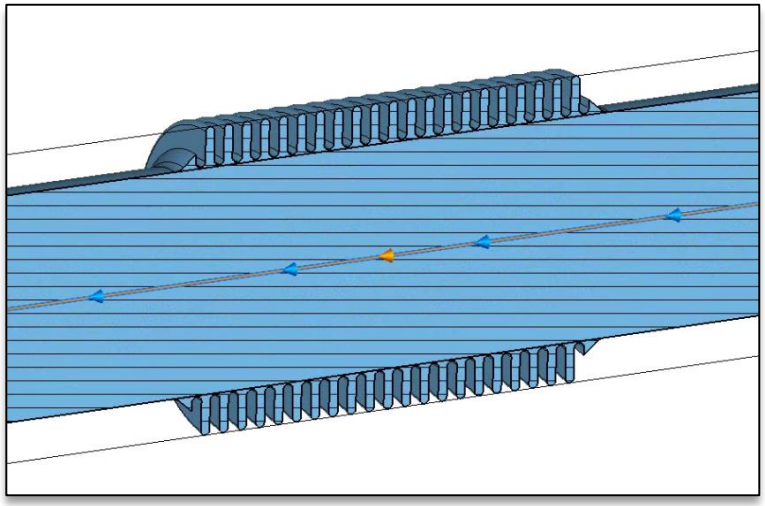


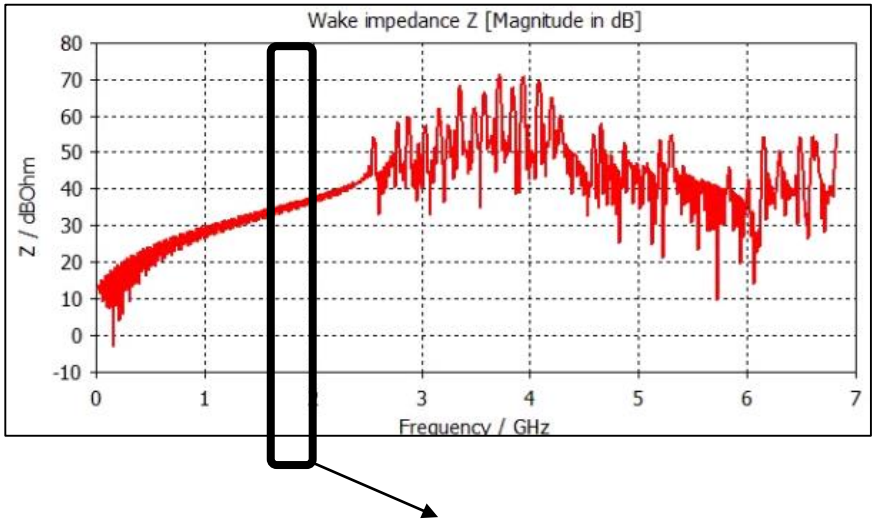
- High resolution narrow band scans also taken on high $Z_{\parallel}$ modes.
- Analytic under-represents power in all cases.
- Large coupling difference seen between modes.

Mode [MHz]	Top HOM Coupler	Bottom HOM Coupler
580	 (b) C2H1 - First modes.	 (c) C1H2 - First modes.
704	 (f) C2H1 - 704 MHz.	 (g) C1H2 - 704 MHz.
960	 (j) C2H1 - 960 MHz.	 (k) C1H2 - 960 MHz.
1263	 (n) C2H1 - 1263 MHz.	 (o) C1H2 - 1263 MHz.

Meas. with Beam: *1.75 GHz*

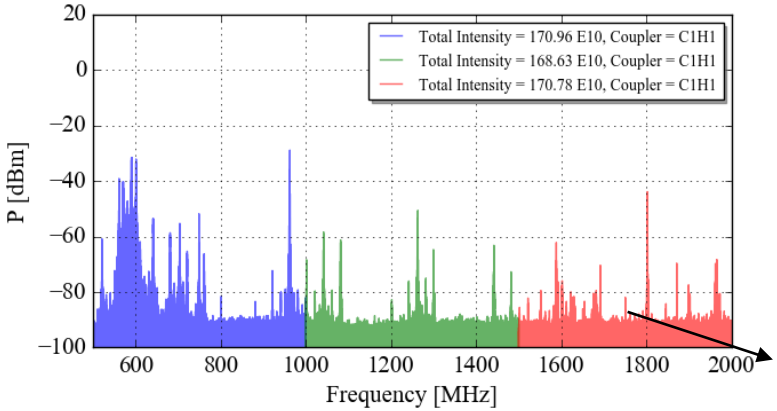
Contribution of a bellow?

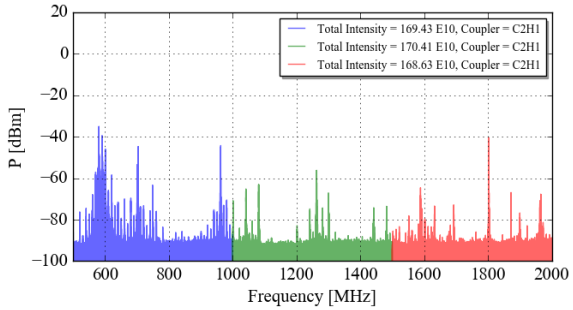




Not bellow impedance.

10/10/2018: MD6: Removed band pass filter on pick-up





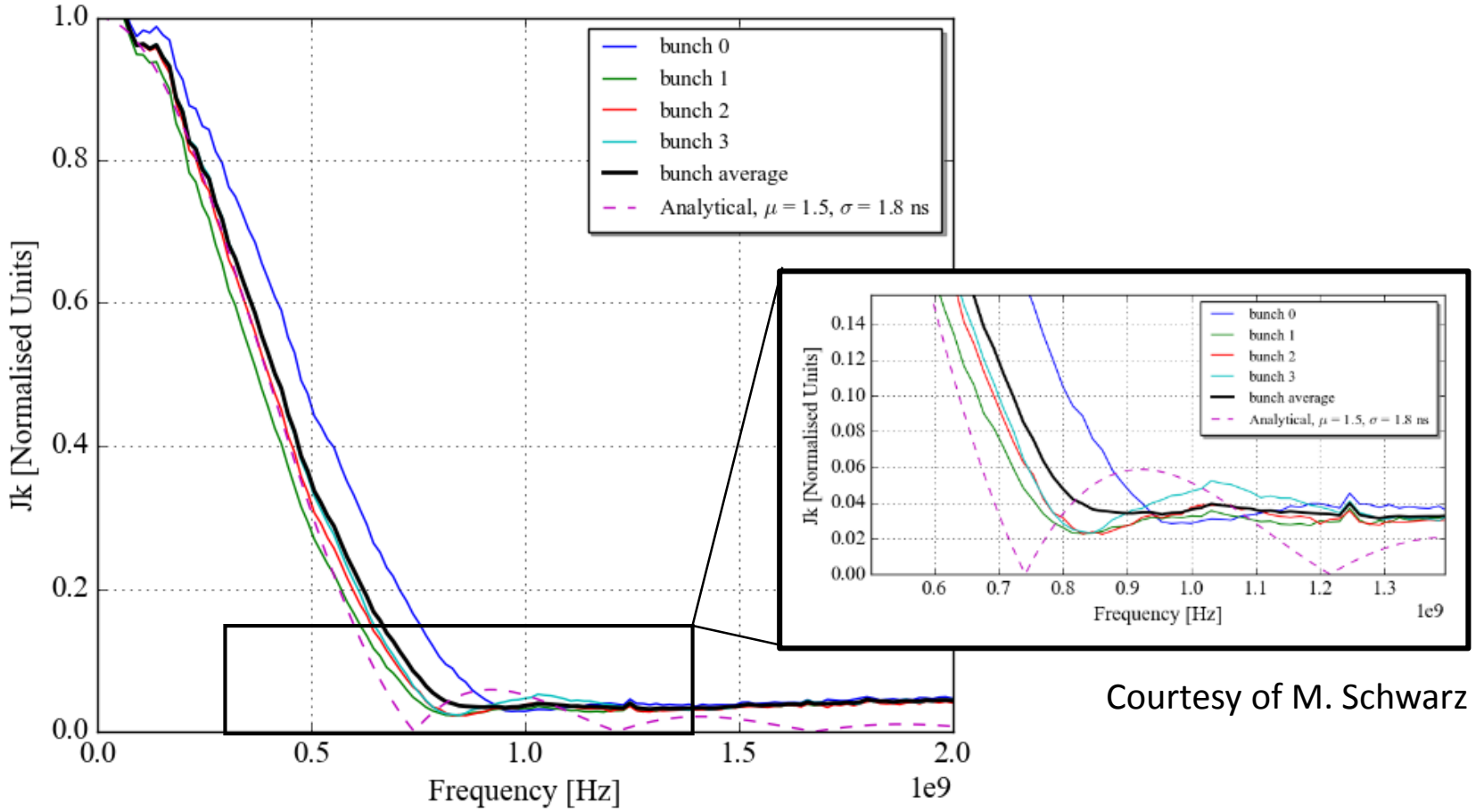
Mismatch on pick-up (HOM damper).

This will not be an issue in the future (see my talk on Thursday!)

Meas. with Beam: *Measured Profile*

05/09/2018: MD5

- To evaluate whether the beam profile was the cause of the underestimation.
- In the following crab cavity test (MD5) the bunch profile was measured during the *coasts*.
- This time multiple bunches were used with a bunch spacing of ~ 525 ns.

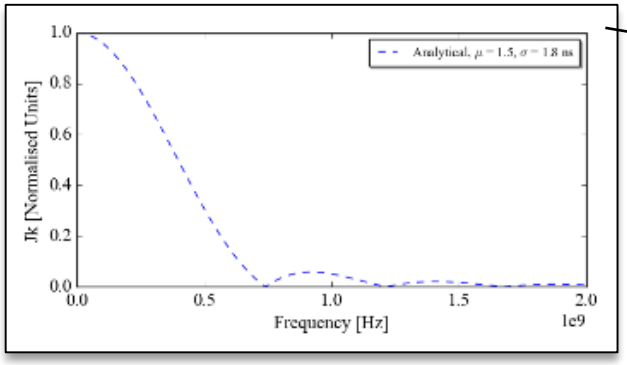


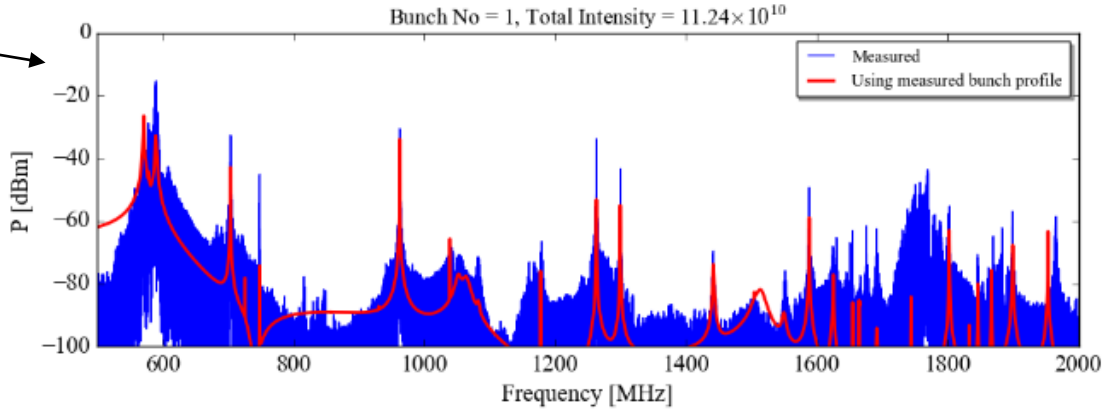
Courtesy of M. Schwarz

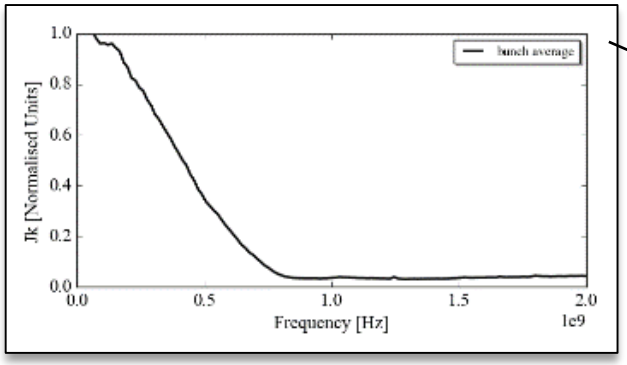
- Conclusion: If HOM is near to binomial 'node': Optimistic and very sensitive to bunch length.

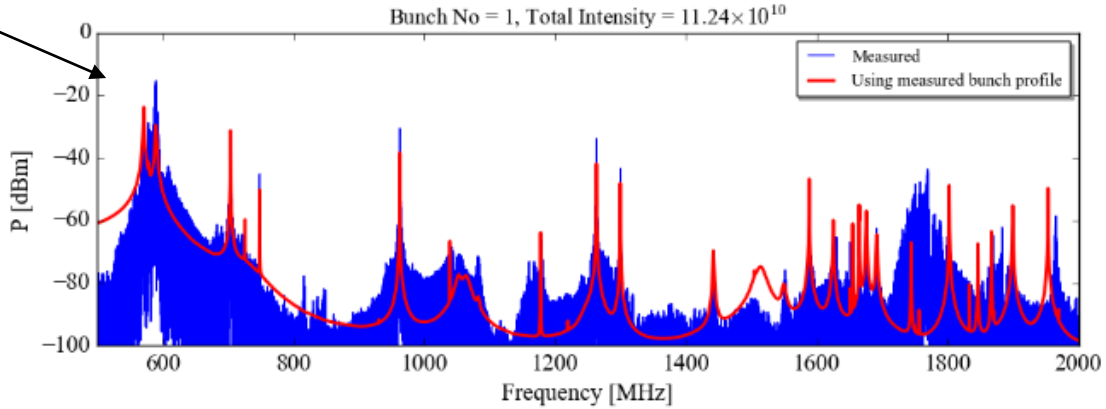
Meas. with Beam: *Measured Bunch Profile*

05/09/2018: MD5





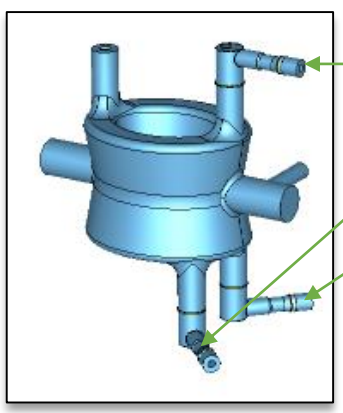


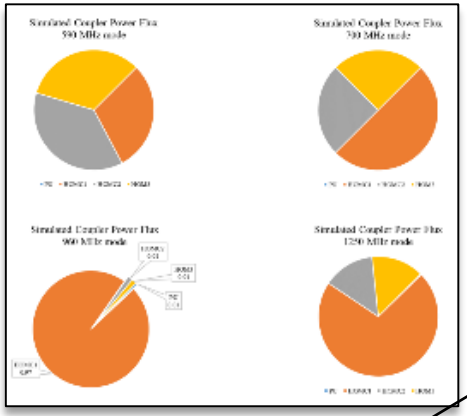


Predicted is total power, not accounting for intra-coupler power flux.

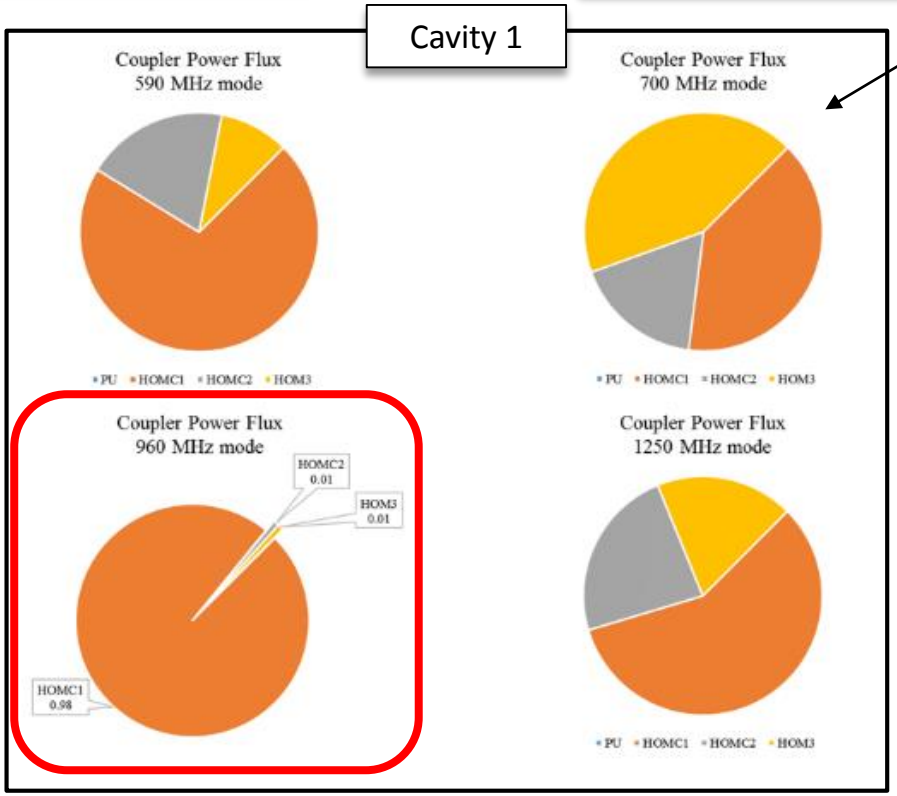
- There are still discrepancies between the measured and analytical.
- This is under investigation:
  - Cable transfer function, mechanical position of HOM couplers, calibrations, bellows etc…

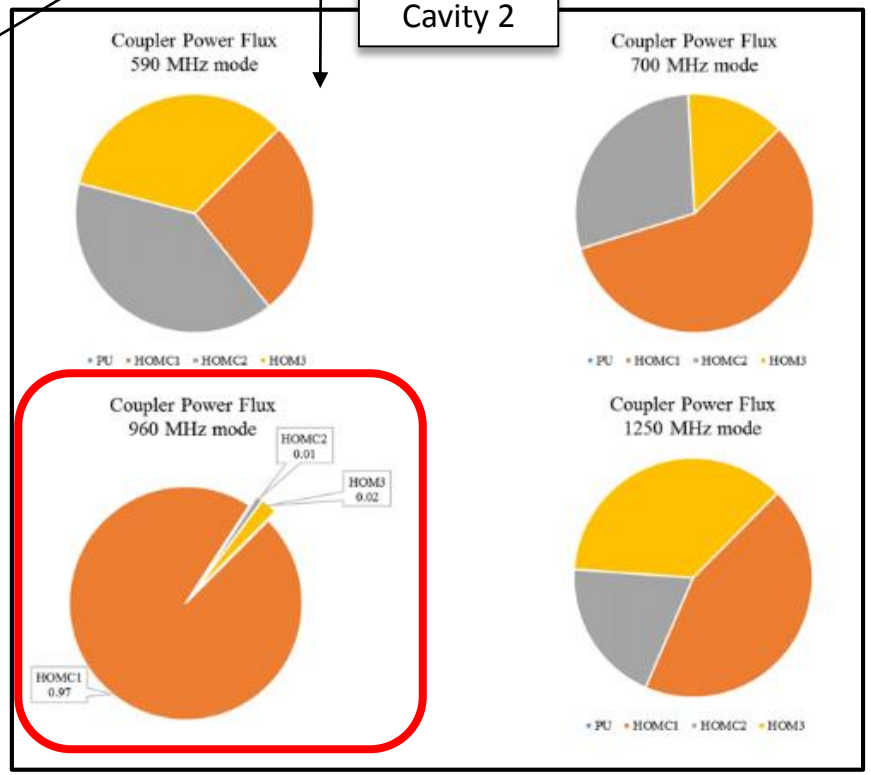
Meas. with Beam: *Power Distribution*





- Measured power ratio for 4 high longitudinal impedance modes.



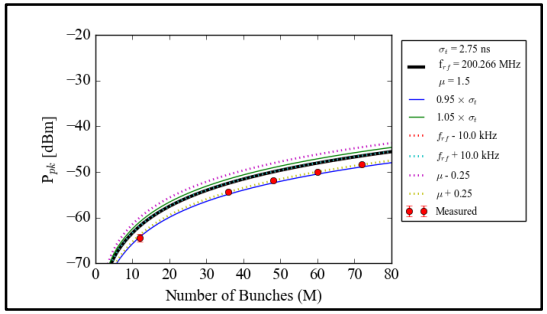


Meas. with Beam: *Multibunch*

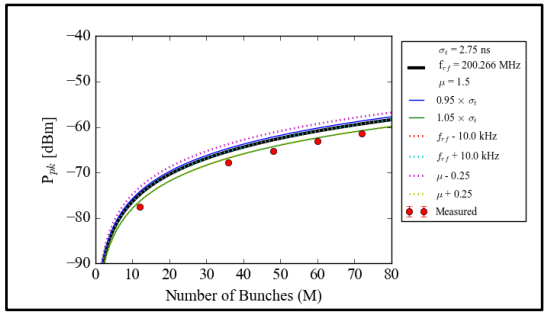
27/08/2018: MD3
Cavity 1

Beam harmonics

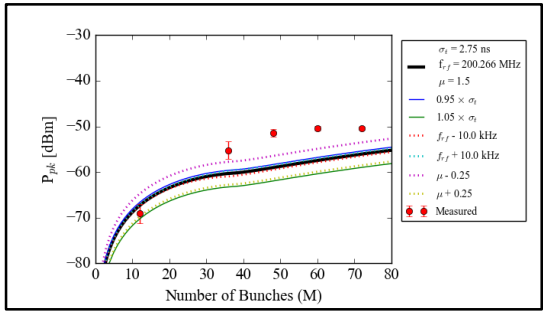
560 MHz



640 MHz

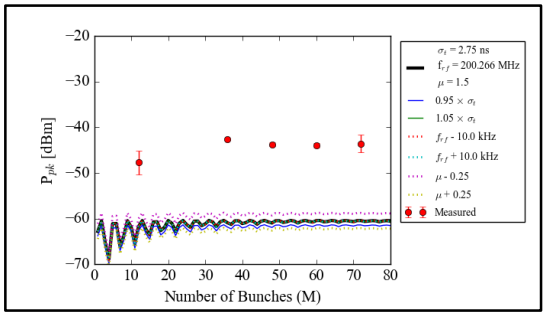


960 MHz

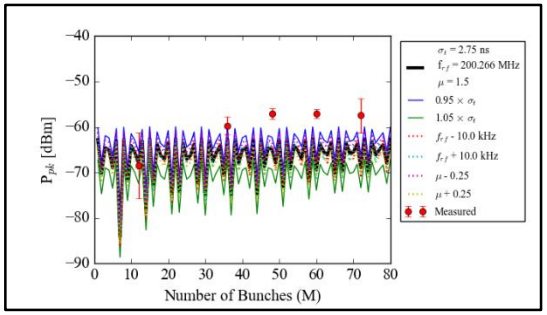


Modes

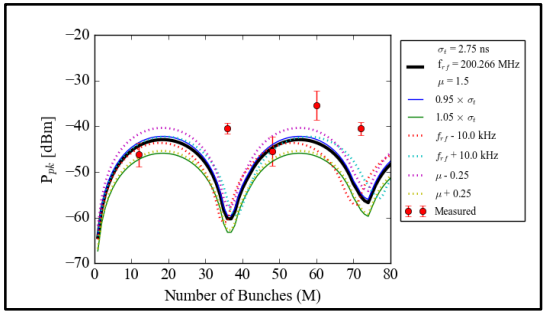
590 MHz



700 MHz



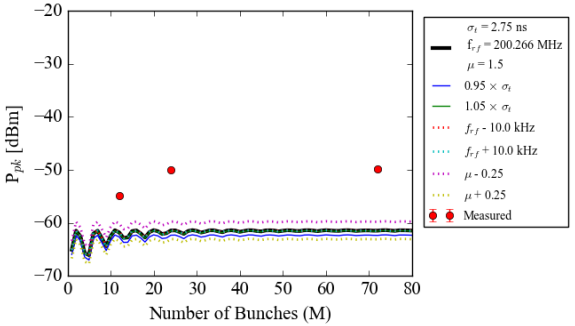
960 MHz



Predicted is total power, not accounting for intra-coupler power flux.

590 MHz mode is underestimated by ~ 15 dB.

- Using measured profile accounts for 5 dB.
- Q or R/Q is underestimated.
- For Cavity 2 the deviation is ~ 10 dB.

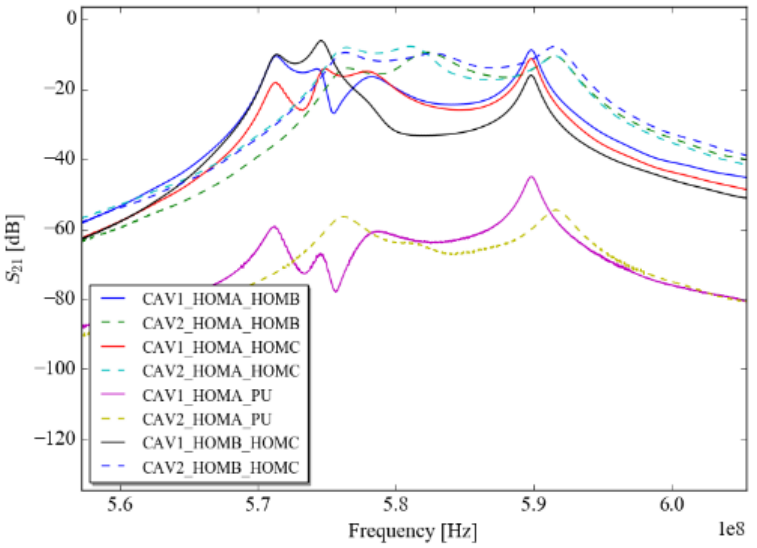


First HOMs

Underestimation in Q or R/Q

- Q measurement could be perturbed by ‘valley-of-modes’.
- Should use ‘poll-fitting’/multi-resonance fitting.

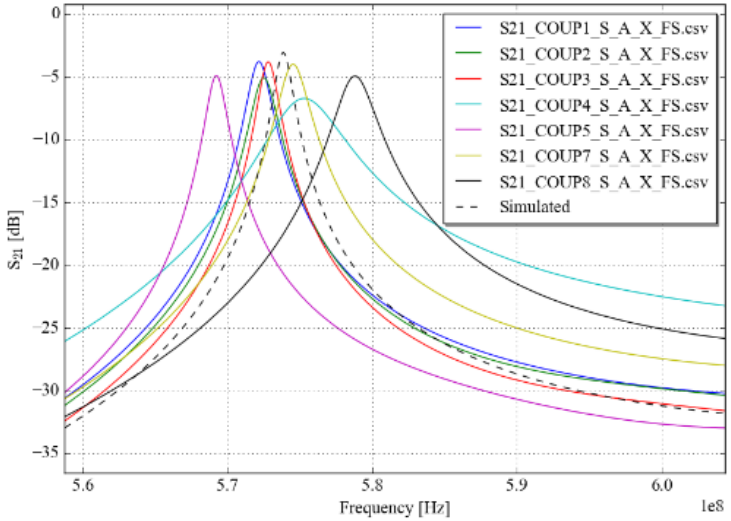
- R/Q could change with alternative tuning.



Inter-cavity differences

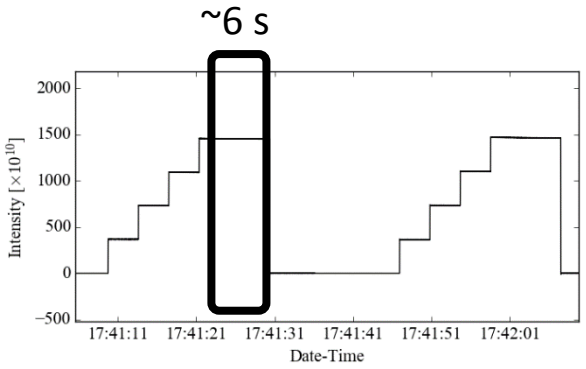
- Test-box measurements of each coupler show the spread in damping.

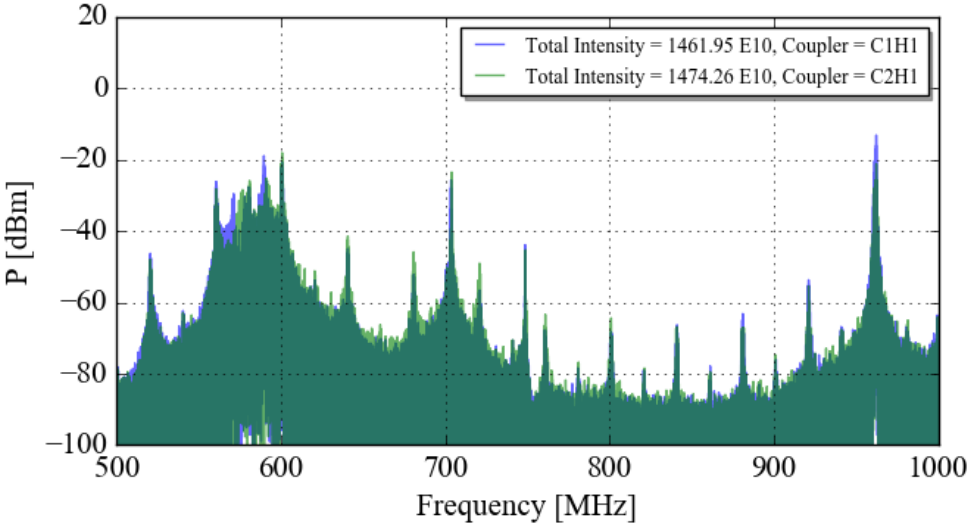
- In the future specific couplers should be chosen for each port!
  - For example, the highest transmission at 960 MHz. should be used as the ‘top-coupler’.

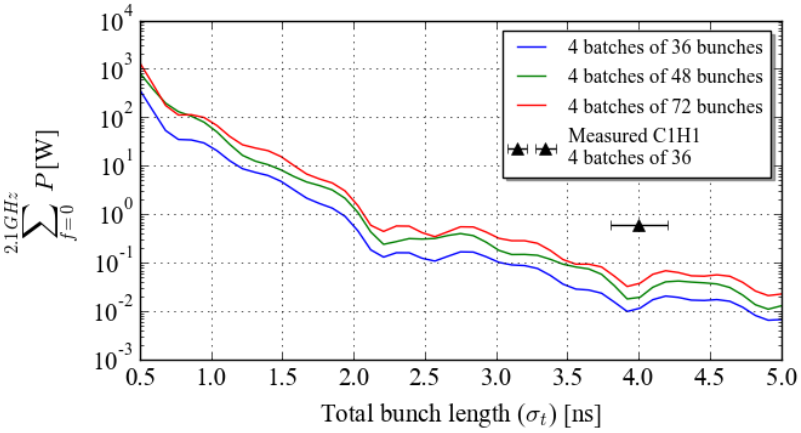


Meas. with Beam: *High Intensity*

- 4 batches of 36 at Np = 1e11
- Power measured at spectrum analyser.
- Low resolution measurement due to filling time of 4 batches.
- 960 MHz mode highest power.
- Around 100 mW peak at cavity (not resolved).







Conclusions

1) **Pre-installation** measurements of HOMs
   - Deviation from simulations.
   - Allow new impedance spectra to be generated.

2) High resolution **broadband** and **single-mode** with **low number of bunches**
   - Unforeseen power at 1.75 GHz – mismatch on pick-up (feed-back antenna).
   - Analytic under-represents – measured profile brings us closer – more analysis of this to come.
   - Mode dependant coupling ratio – all power at 960 MHz (most detrimental mode) through top coupler (see my Thursday talk).

3) Mode power as a function of **bunch number**
   1) Big deviation for 590 MHz mode – investigations into Q, R/Q and I(ω).

4) High Intensity
   1) Ongoing analysis.

- On-going work: longitudinal and transverse R/Q measurement.

…Thanks again to Rama, Lee and Graeme.