Update on DQW HOMs

J. A. Mitchell [1, 2]

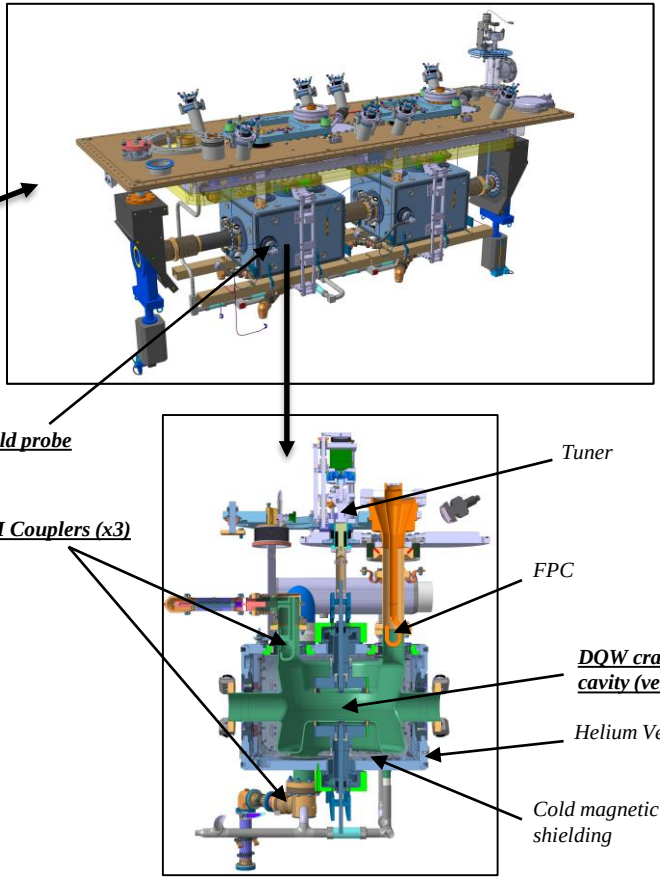
[1]Engineering Department, Lancaster University: *Graeme Burt*

[2]BE-RF Section, CERN: *Rama Calaga*

131st HL-LHC WP2 Meeting

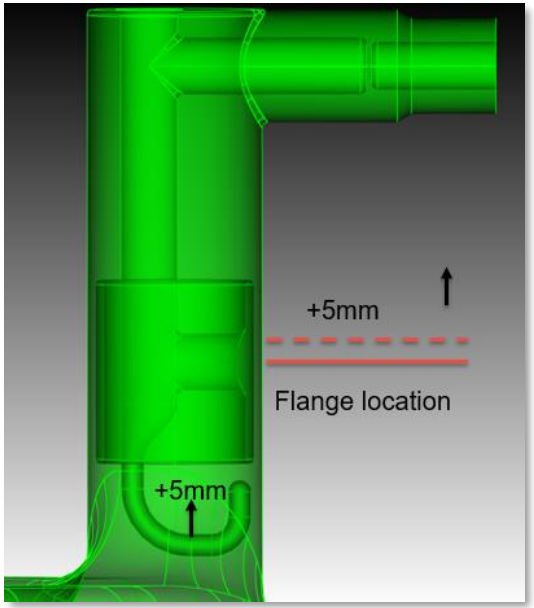
CERN-Internal, 25th September 2018

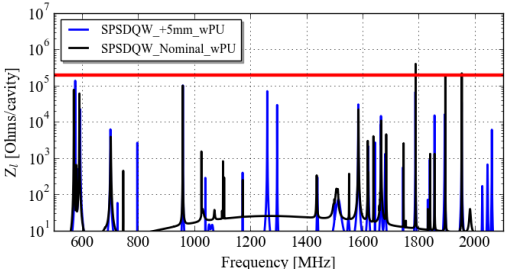
SPS Crab Test Stand

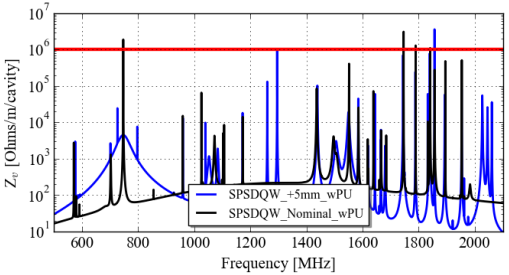


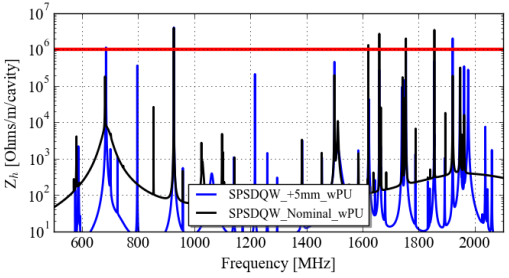
Ancillaries: *Non-conformity*

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



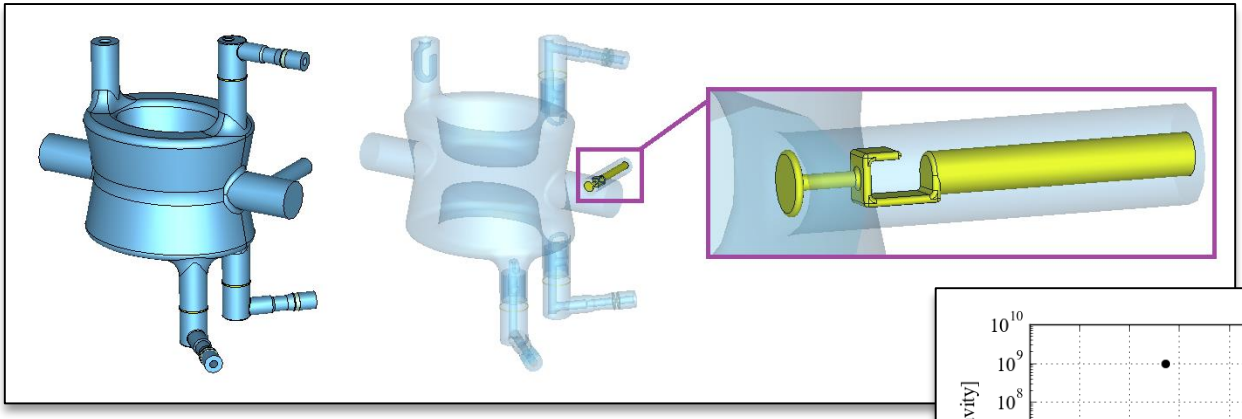


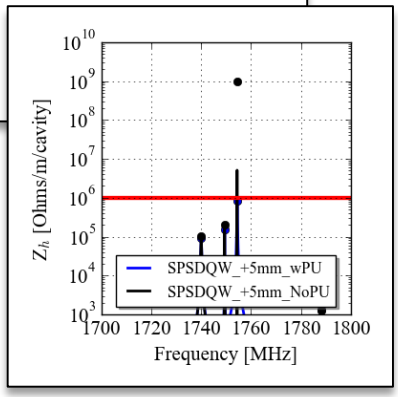




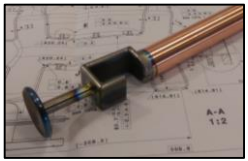
Ancillaries: *Field probe as fourth HOM coupler*

- 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 1.75 GHz mode → cannot couple to this mode with HOM couplers.



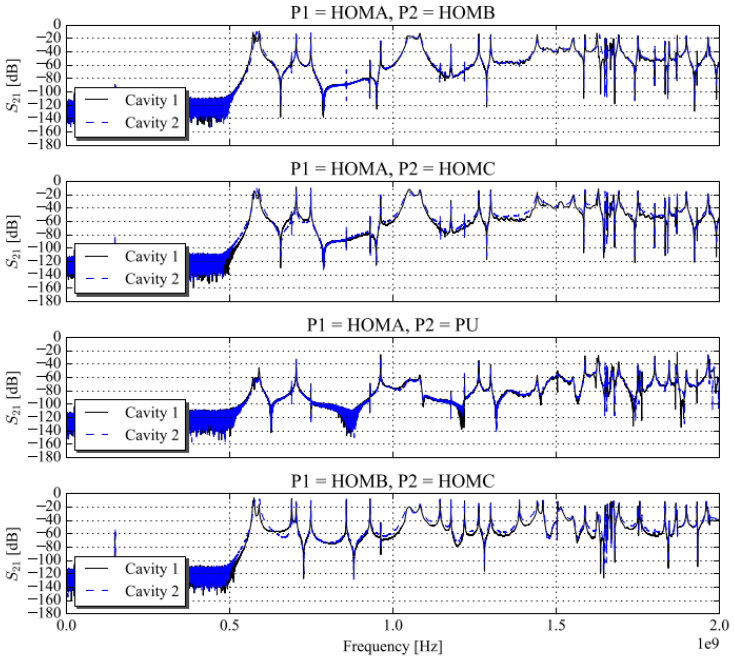


- The PU is made from Nb and Cu to avoid heating.



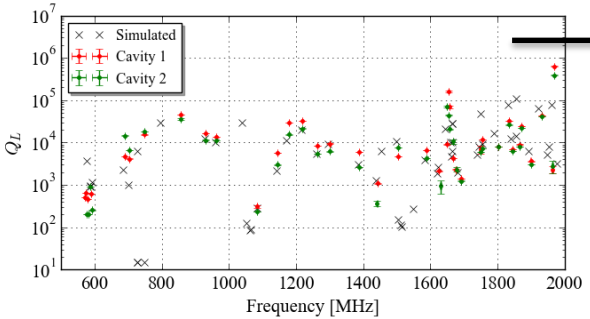
Mode measurements

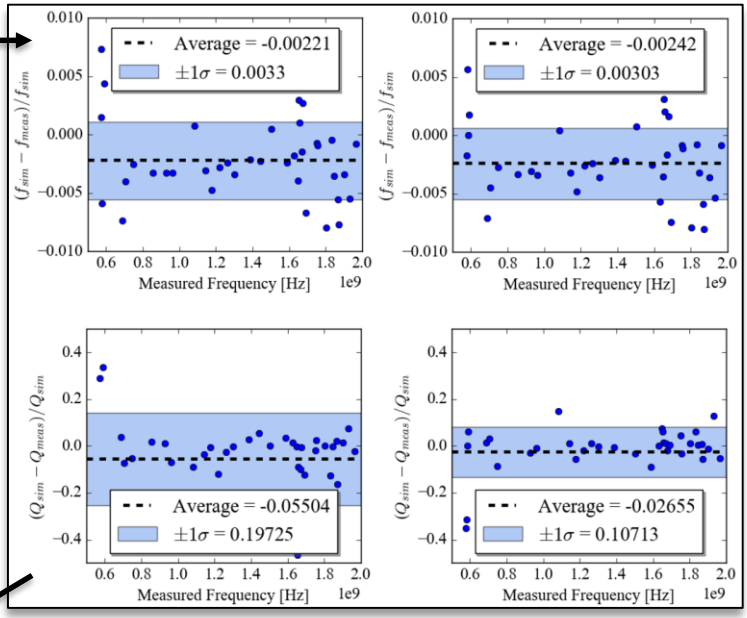
- Transmission measurements using VNA in cryomodule cold test in M7 buncker.



Mode measurements

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





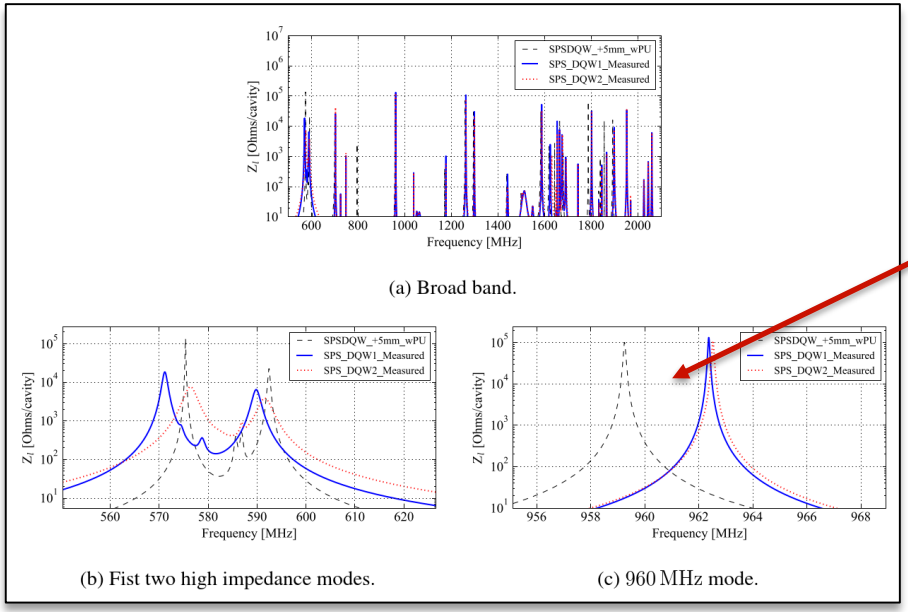
Deviations are hence:

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

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

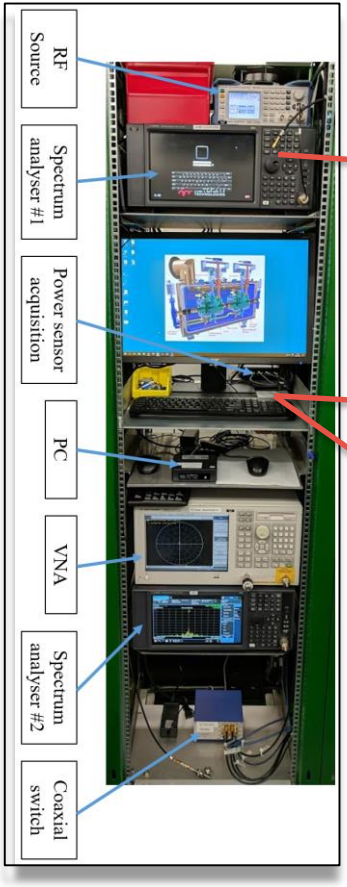
Modified impedance spectra

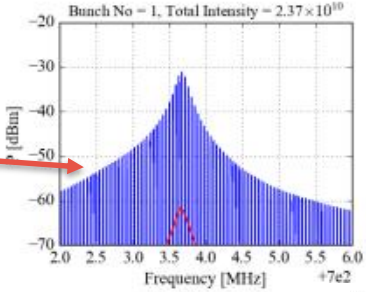
- Impedance spectra:
  - Frequencies and Q_e values are known for a large number of modes.
  - **<u>Simulated spectra altered for both cavities.</u>**
  - Note, remembering to use the +5 mm simulation results!

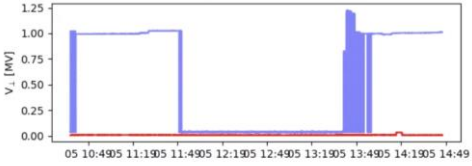


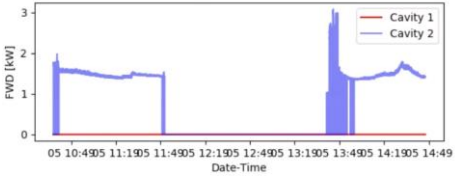
- For both cavities the 960 MHz mode has increased in frequency.
- From BELOW to ABOVE the harmonic!
- This shows it is feasible for the mode to be excited by the 24th harmonic at 25 ns bunch spacing

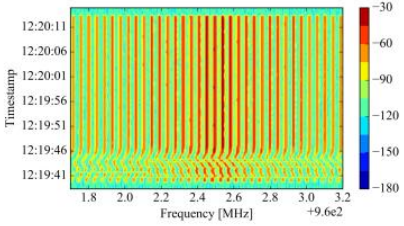
Measurements with beam: *Test-stand*







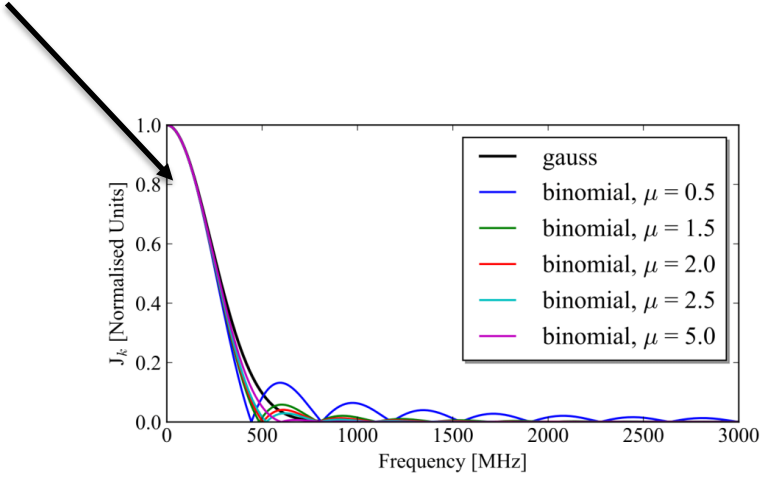




Measurements with beam

- **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.**

- A binomial distribution was initially used to represent the bunch profile.



Meas. with Beam: *Broadband*

- Single bunch HOMC1:

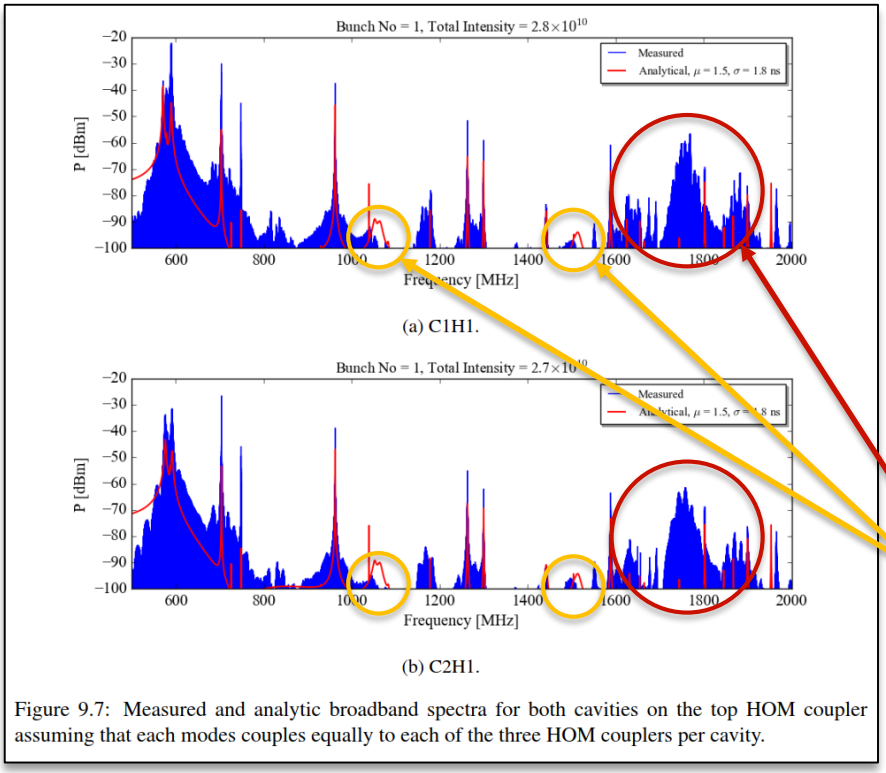
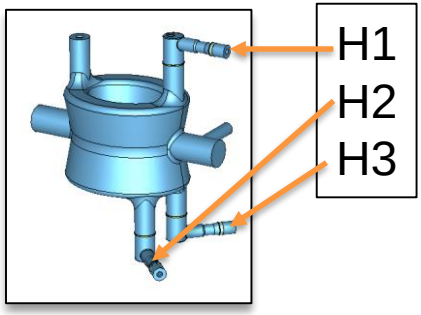
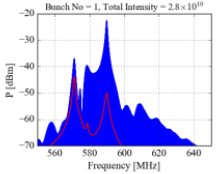


Figure 9.7: Measured and analytic broadband spectra for both cavities on the top HOM coupler assuming that each modes couples equally to each of the three HOM couplers per cavity.

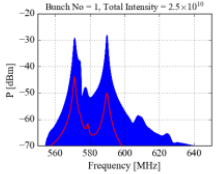


- General form is well represented.
- Analytic underestimates for all modes.
- Unforeseen power at 1.8 GHz.
- Missing power at 1.1 and 1.5 GHz.

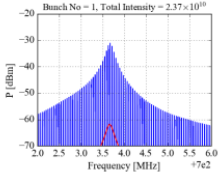
Measurements with Beam: *Narrow-band*



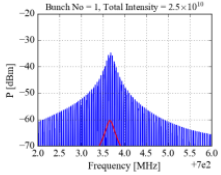
(a) C1H1 - First modes.



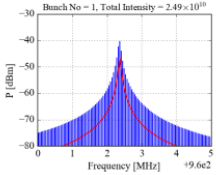
(c) C1H2 - First modes.



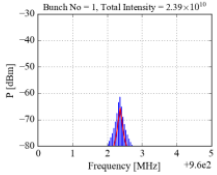
(e) C1H1 - 704 MHz.



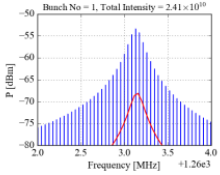
(g) C1H2 - 704 MHz.



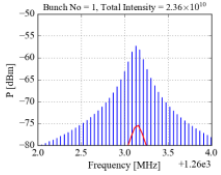
(i) C1H1 - 960 MHz.



(k) C1H2 - 960 MHz.



(m) C1H1 - 1253 MHz.



(o) C1H2 - 1263 MHz.

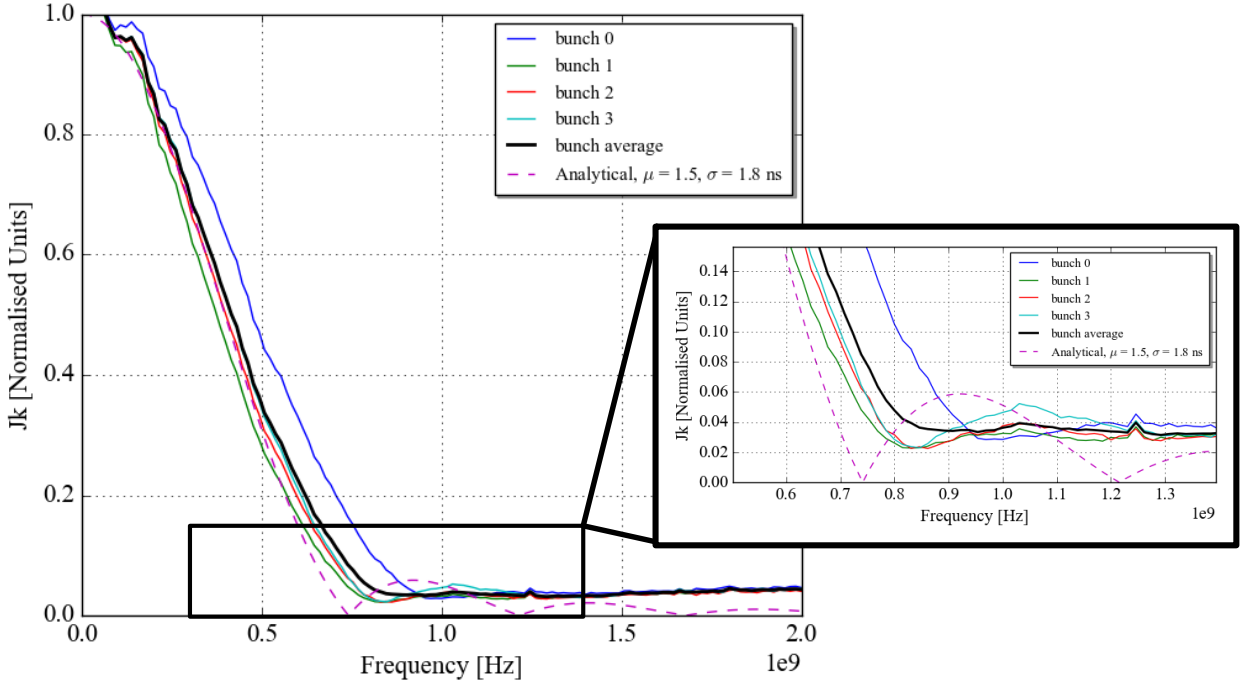
- High resolution narrow band scans also taken on high longitudinal impedance modes.

- Analytic under-represents power in all cases.
- Large coupling difference seen between modes.

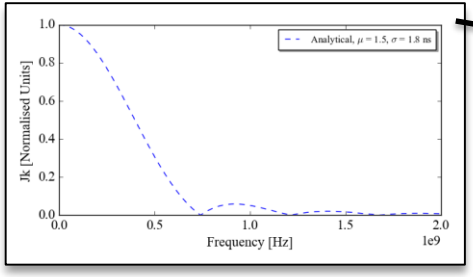
- Moving forward:
  1. Measure bunch profile.
  2. Evaluate whether the difference in coupling is realistic or an artefact of the measurement set-up.
  3. Evaluate extra high-frequency power.

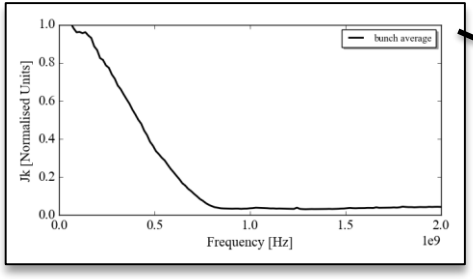
Measurements with Beam: *Bunch Profile*

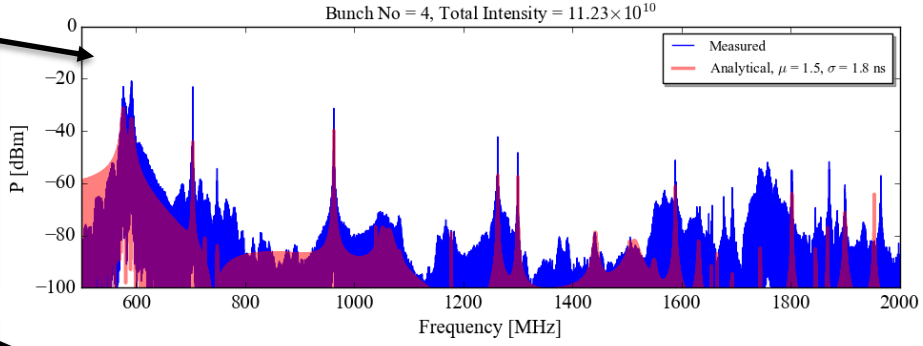
- In the following crab cavity test (MD5) the bunch profile was measured during the *coasts*.
- This time multiple bunches were used with a bunch spacing of ~ 525 ns.

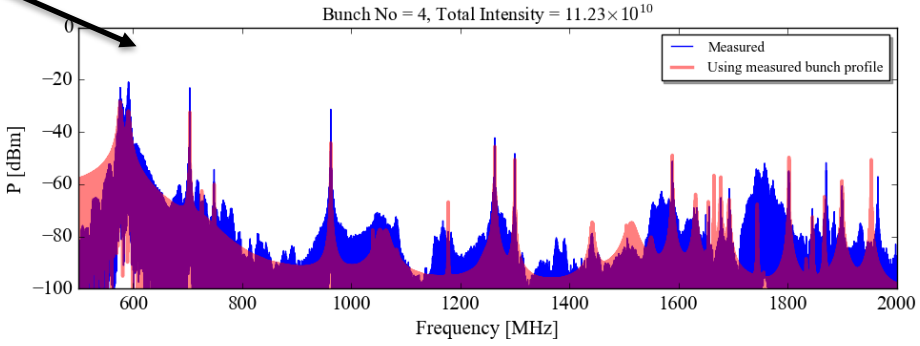


Meas. with Beam: *Measured Bunch Profile*







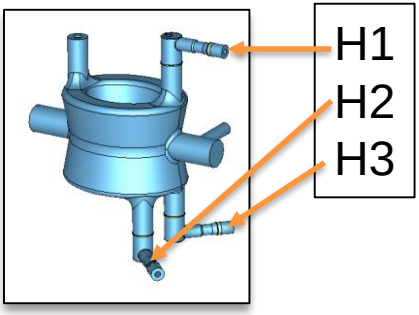


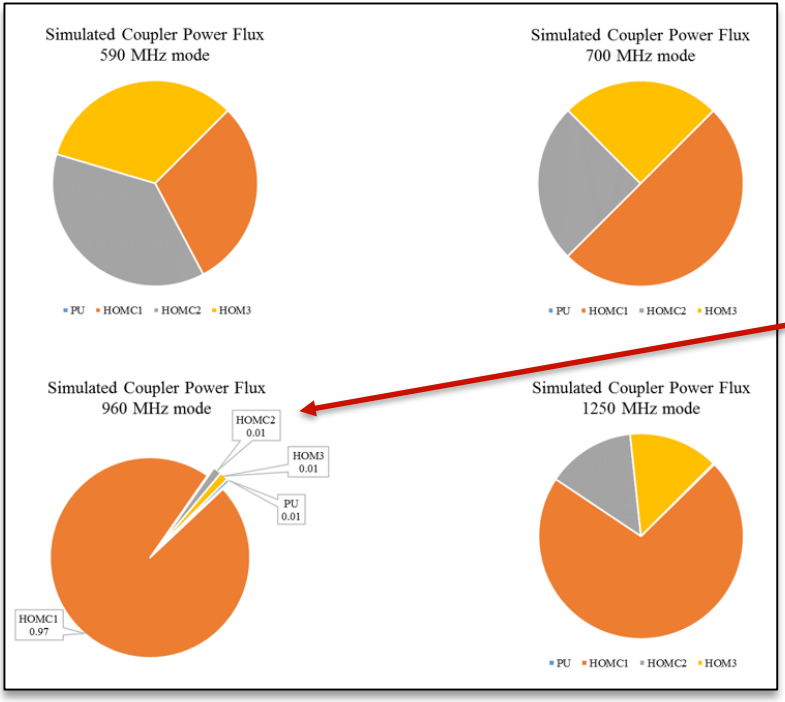
Predicted is total power, not accounting for intra-coupler power flux.

- Measured much closer to predicted – especially at high frequency.
- With multiple bunches - small changes and spread in bunch spacing can make a large difference.
- Couplers could be inserted further than expected – metrology will tell us…
- **Conclusion – pessimistic bunch profile should be used in power calculations.**
  - *… This feedback is incredibly useful for heat-load assumptions for the LHC!*

Meas. with Beam: *Power Distribution*

- Need to evaluate the **simulated** coupling differences.



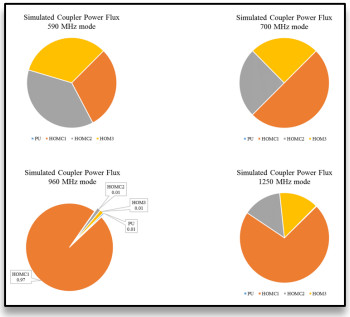


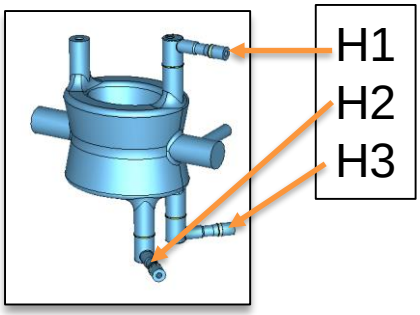
Note, **960 MHz** mode has power flux only trough **HOMC1**.

Reduction in total power for each coupler [dB]

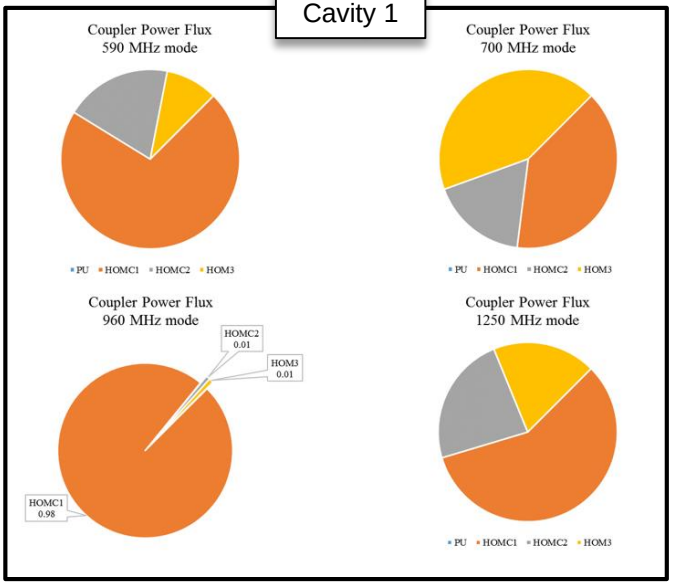
f [MHz]	PU	HOMC1	HOMC2	HOMC3
586.94	38.74	5.27	4.28	4.83
959.16	22.99	0.14	18.65	18.54
700.57	36.19	3.01	6.01	6.03
1259.76	27.14	1.45	8.56	8.47

Meas. with Beam: *Power Distribution*

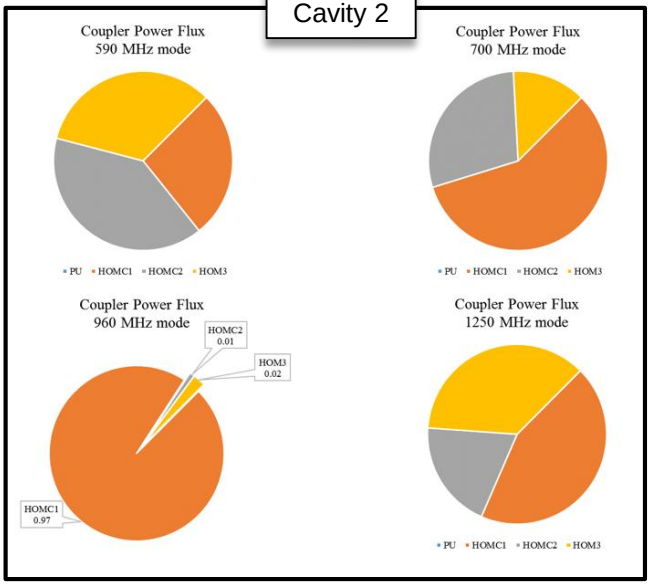




Cavity 1



Cavity 2



Meas. with Beam: *Conclusions*

- Moving forward:
  1. Measure bunch profile.
  2. Evaluate whether the difference in coupling is realistic or an artefact of the measurement set-up.
  3. Evaluate extra high-frequency power.

Current assumed profile is not representative.
In the future, for HOM coupler development we should use a more realistic bunch form.

Difference in coupling is expected in simulation and is reproducible in measurements.

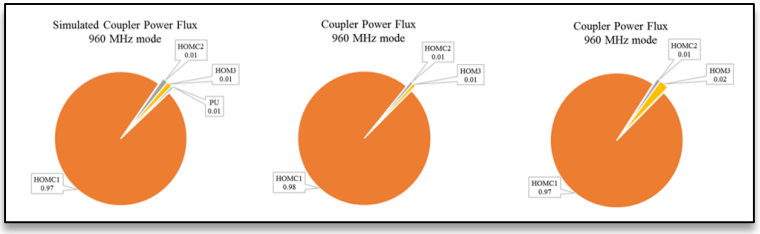
Further investigations on-going. Simulations of unshielded bellows are under-way.

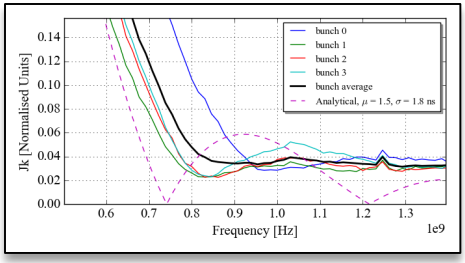
HOM Coupler Dev. : *Meas. feedback*

For HL-LHC it is the 960 MHz mode which is capable of causing the highest heat load.

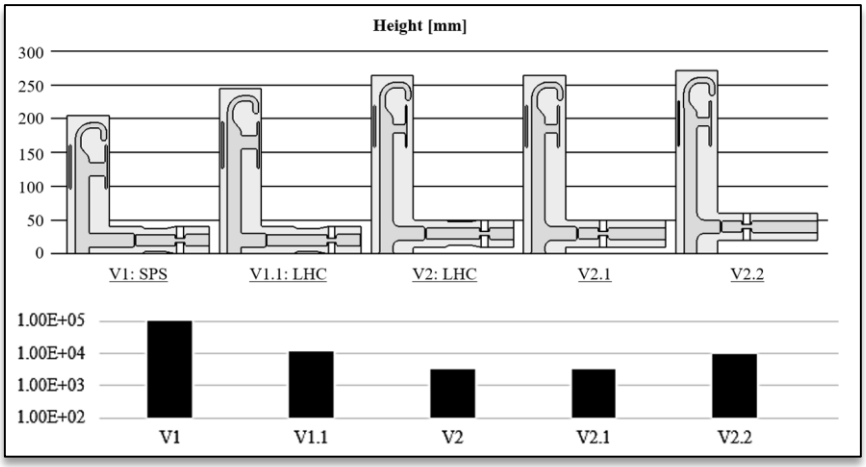
1) All power at 960 MHz couples to top HOM coupler

2) Bunch profile is pessimistic





960 MHz, Z_l [Ohms/cavity]



Meas. with Beam: *Measurements taken*

Above cut-off frequency

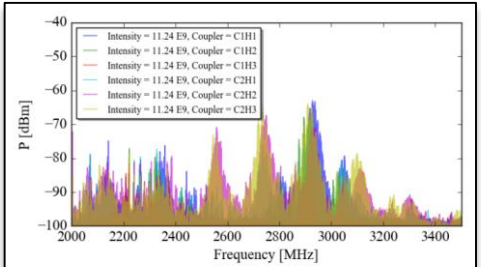


Figure 9.19: Above beam pipe cut-off frequency.

Field probe

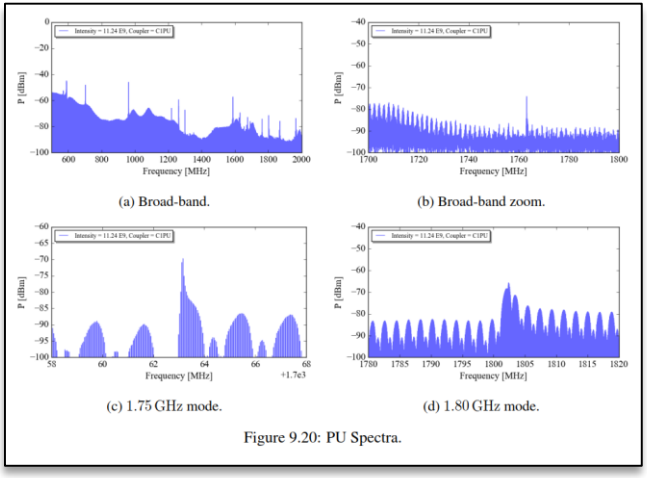


Figure 9.20: PU Spectra.

High resolution of high-Q modes

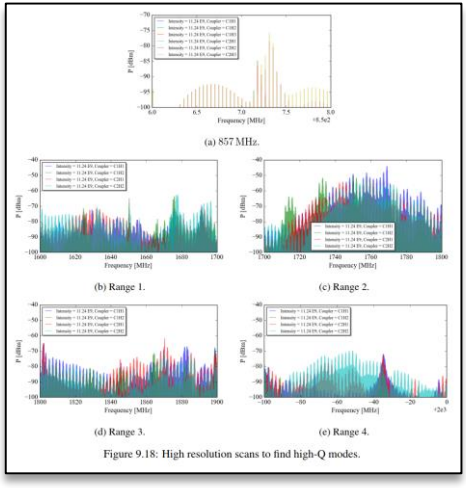
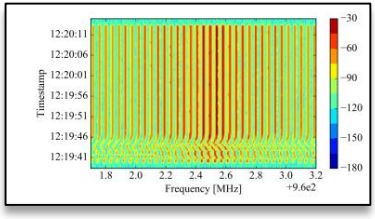


Figure 9.18: High resolution scans to find high-Q modes.

Power variation with energy ramp



… and multibunch

Conclusions and Next steps

Conclusions

- The form of the spectral power matches what we expect.
- To predict the amplitude accurately we need to better model the I(ω).
- The 960 MHz mode couples only to the top HOM coupler *Significant for LHC design*
- Un-forseen power at 1.8 GHz
- No modes that were not simulated and no modes with significant increase in Qe.

Next steps

- Further analysis of multi-bunch data – with better I(ω).
- Reconstruct cavity impedance spectra.
- Multi-bunch measurements in next MDs.
- Off-Axis measurements – I have a measurement proposal for Rama and Lee.