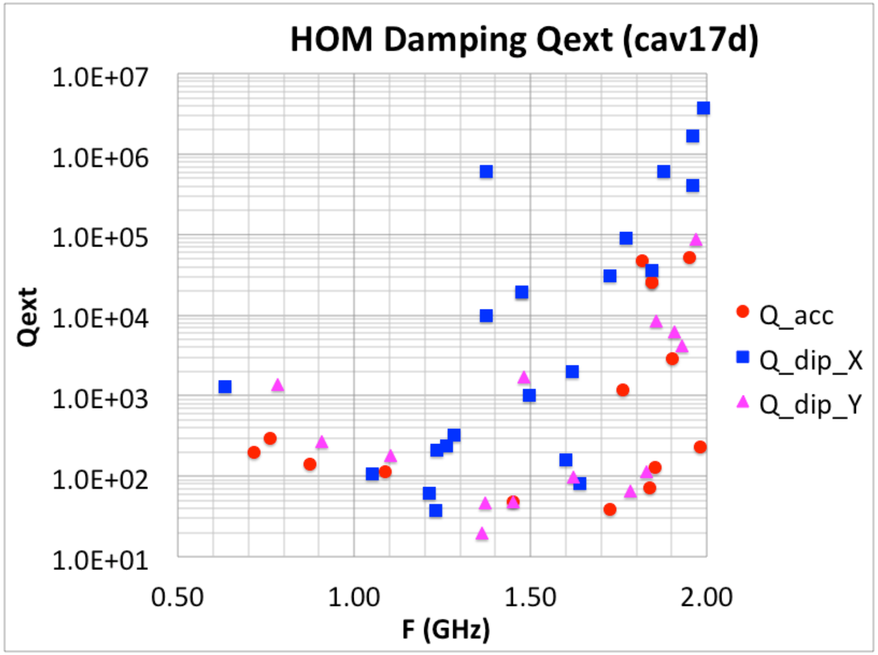
The Cockcroft Institute
of Accelerator Science and Technology

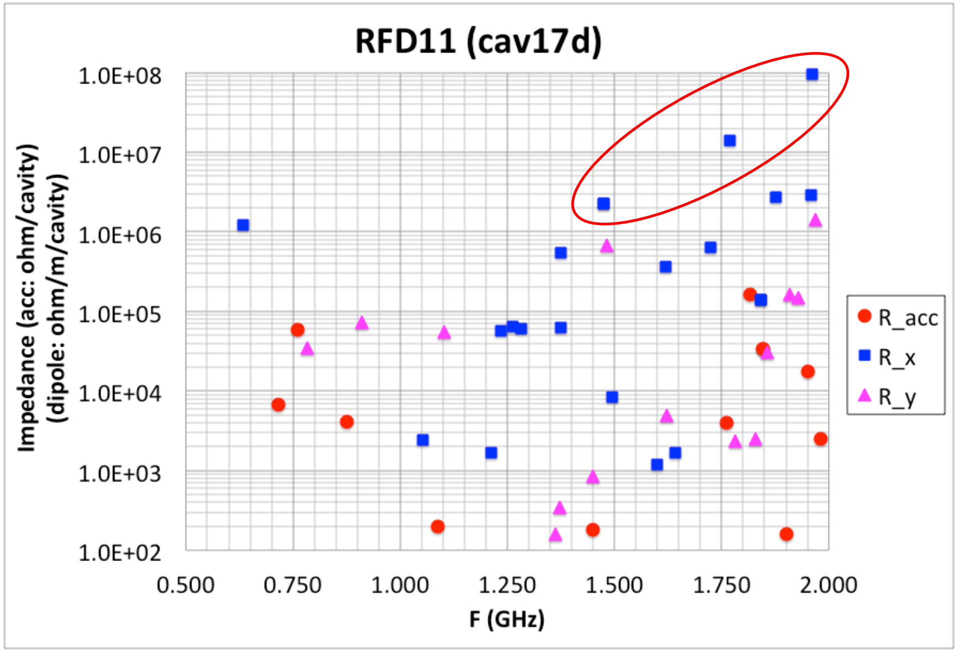
Wake Impedance Calculations

G. Burt, Lancaster University
Thanks to Rama Calaga, Benoit Salvant, Binping Xiao, Suba DeSilva and Zenghai Li.

Recommendations from HOM Review

Presented at Feb 2015 Engineering Review Z. Li





(no 1/2 factor in impedance calculation)

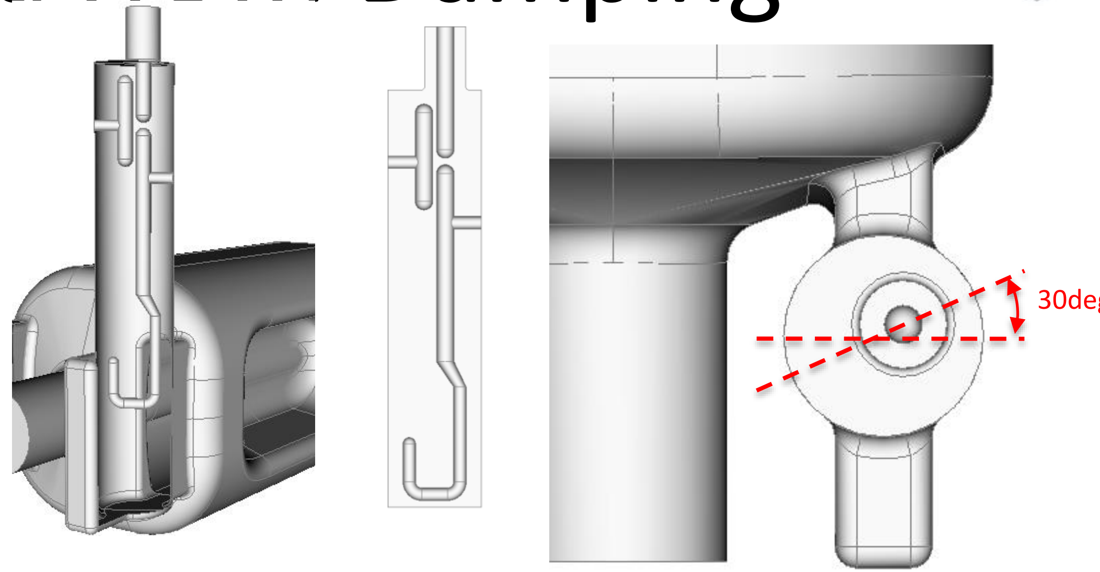
- Reviewer suggested to take a look at a few higher impedance modes at higher frequencies, (though not critical for SPS test)
- Modified H-HOM hook and V-HOM probe → Reduced impedance by 1-2 orders of magnitude

Slide courtesy of Suba and Zenghai

Improved HOM Damping

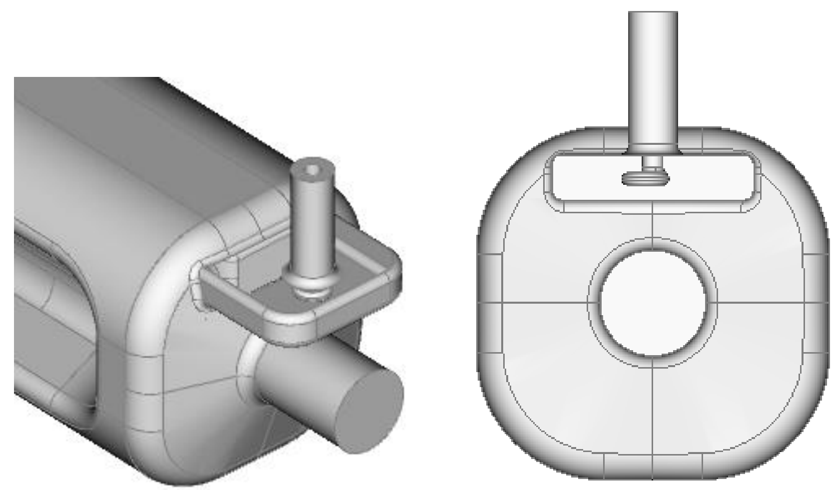
Horizontal HOM Coupler

- Coupling hook optimized
- 30 degree hook orientation
- No change in filter elements



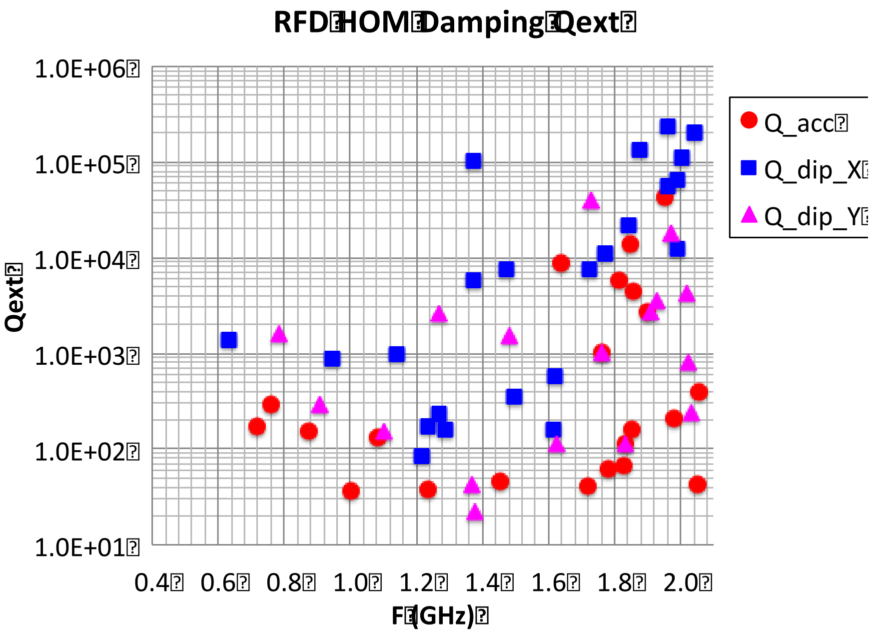
Vertical HOM Coupler

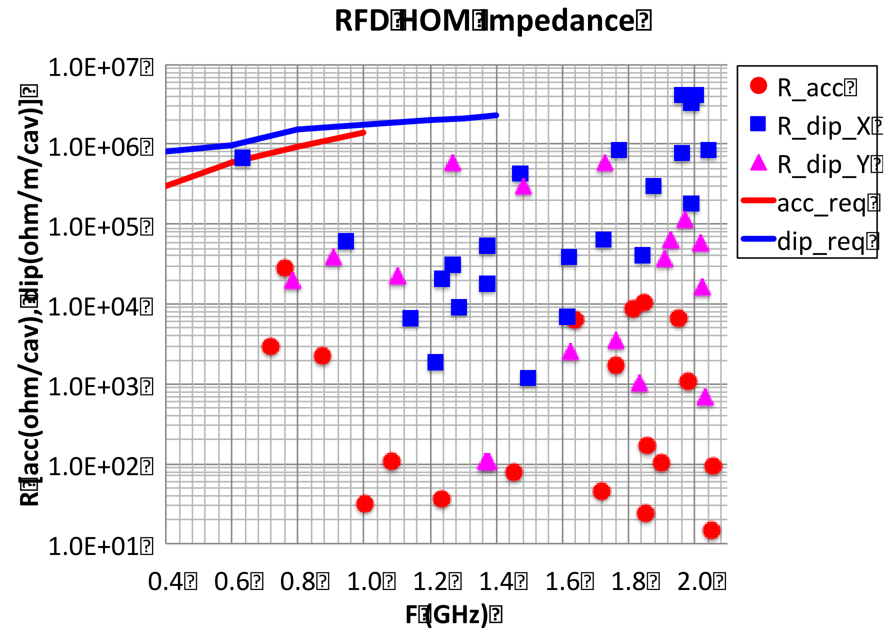
- 7 mm offset incorporated into the pickup tip to enhance coupling to the dipole modes at around 2GHz
- Small RF power leakage through the coupler, ~1.5W, due to asymmetry



Slide courtesy of Suba and Zenghai

HOM Damping and Impedance

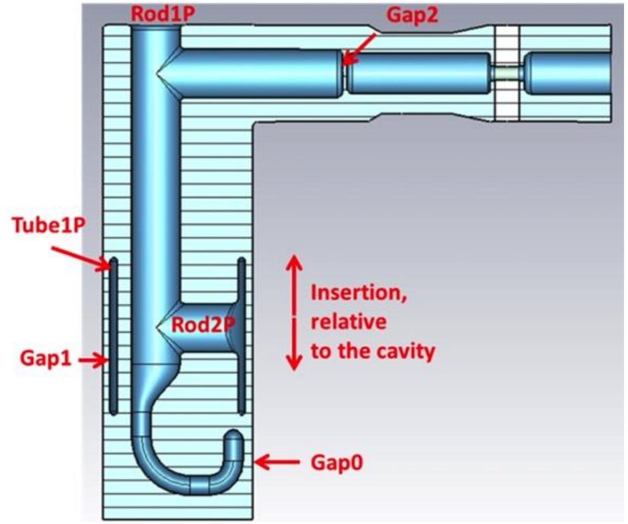


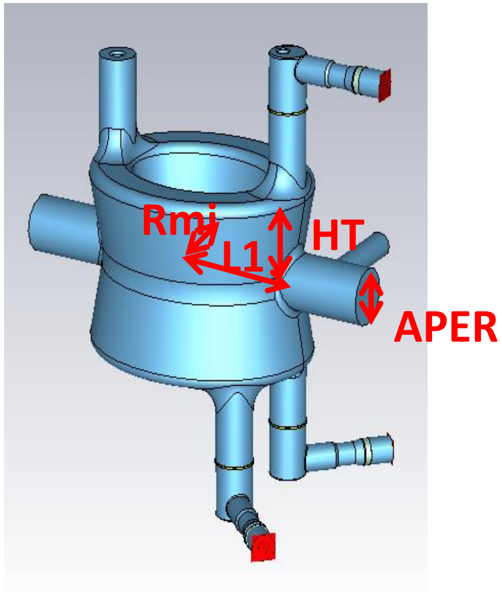


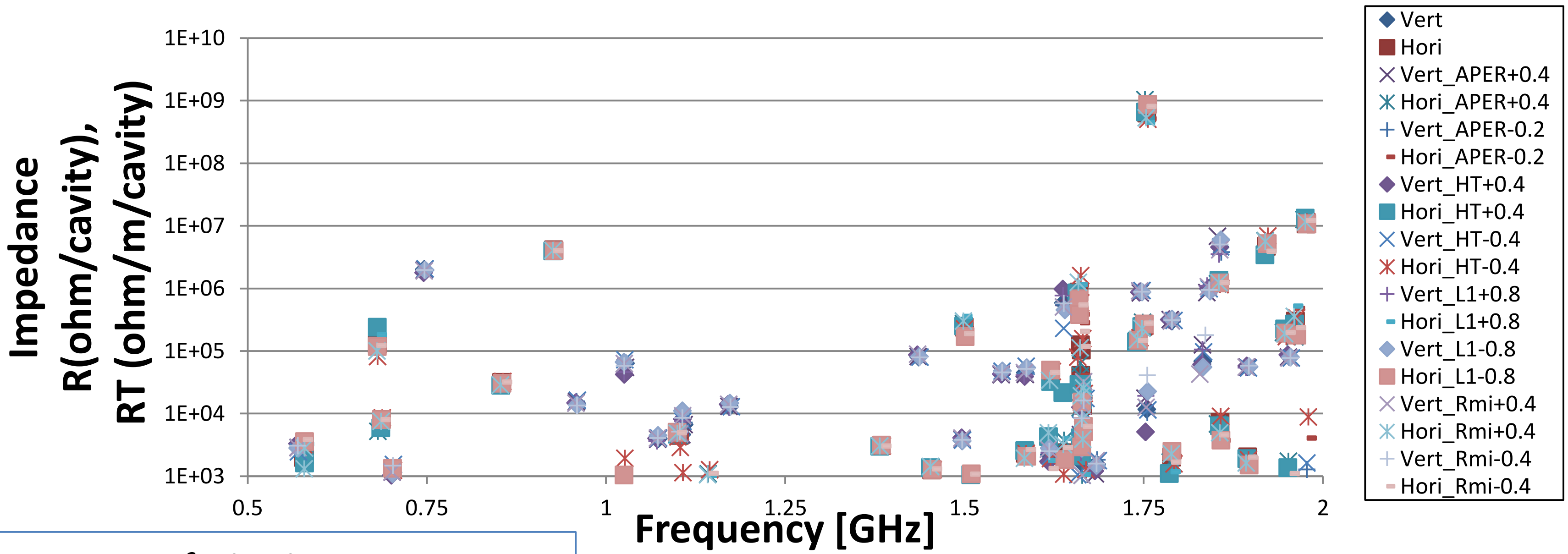
- Q_{ext} calculated using Omega3P for modes up to 2 GHz
- Solid lines are the impedance budget for dipole HOMs (blue) and accelerating HOMs (red) respectively
- Damping scheme meets the impedance requirement (2011)

Slide courtesy of Suba and Zenghai

HOM with fabrication errors

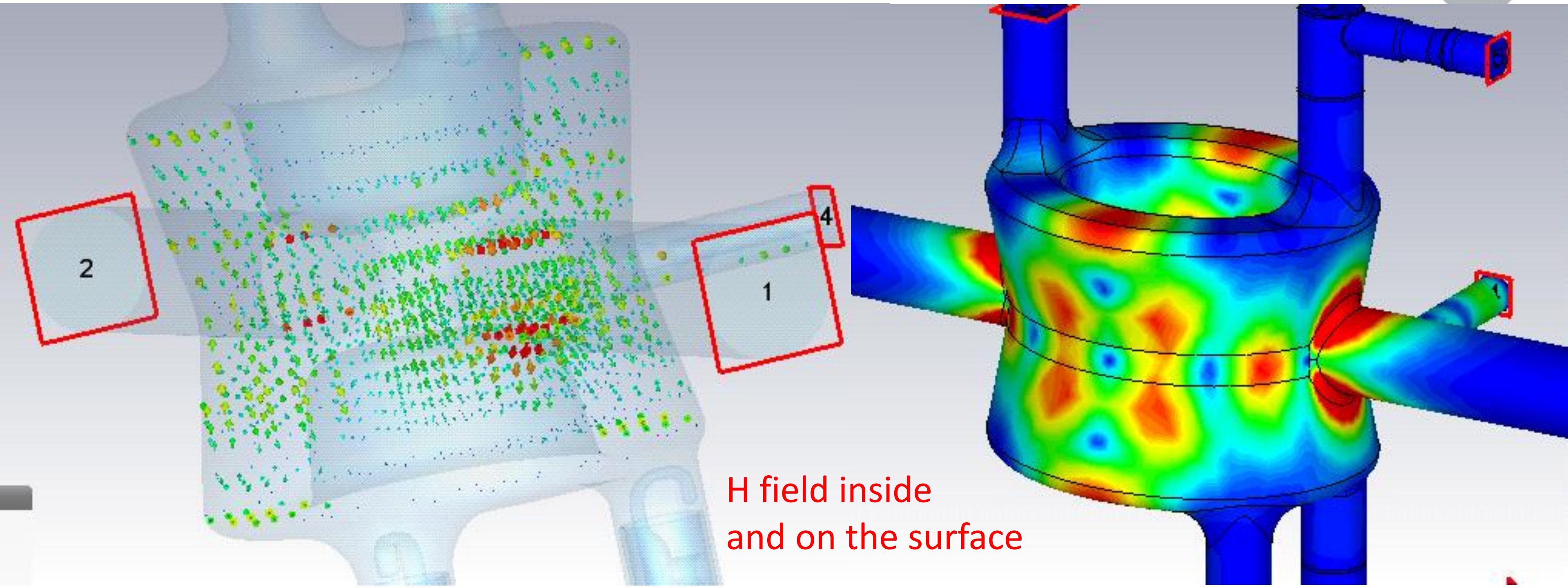






Slide courtesy of Binping

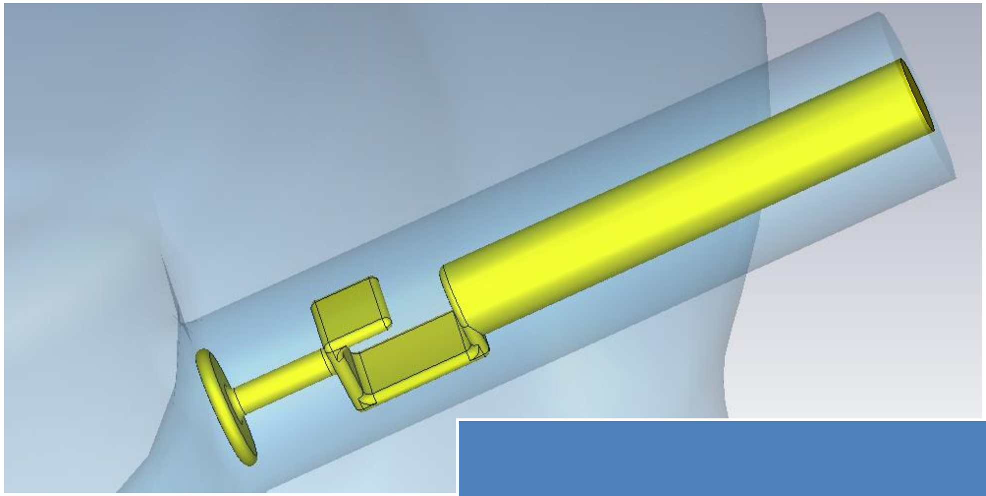
Possible solutions for 1.75GHz



- Change the coupling positions
- Improve filter S21 @ 1.75GHz
- Change length of inner conductor
- Change the direction of the HOM filter feedthrough with respect to the hook

Slide courtesy of Binping

Current PU design



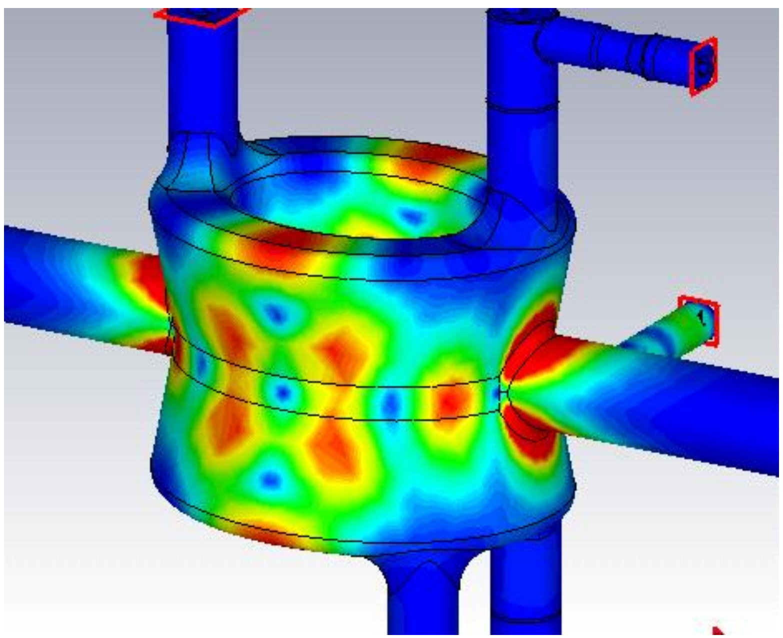
Add a "T" on top of the original PU coupler

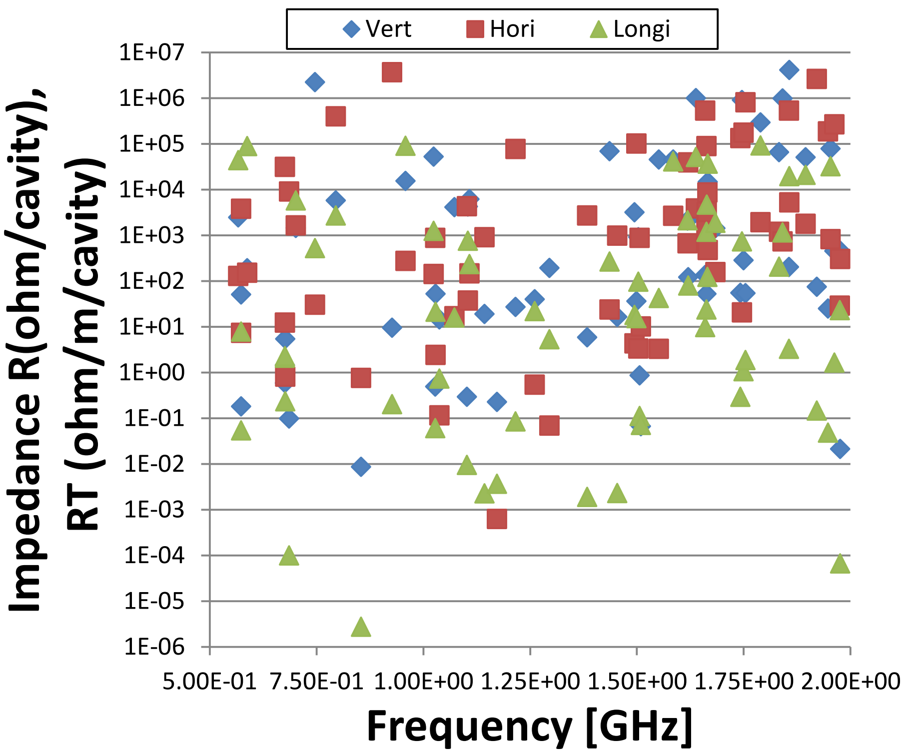
	Modified PU	Original PU
Qext @ 1.75 GHz (from PU and HOM couplers)	9616	7.27e6
Horizontal shunt impedance (Ω/m/cavity, in circuit definition)	8.39e5	6.34e8
Qext @ 400 MHz (from PU coupler)	1.6e10	1.6e10
Pickup power at 3.34MV (W)	1.57	1.57
Power dissipation at PU at 400MHz (for 20nΩ Nb PU)	26.5µW	

Slide courtesy of Binping

DQW

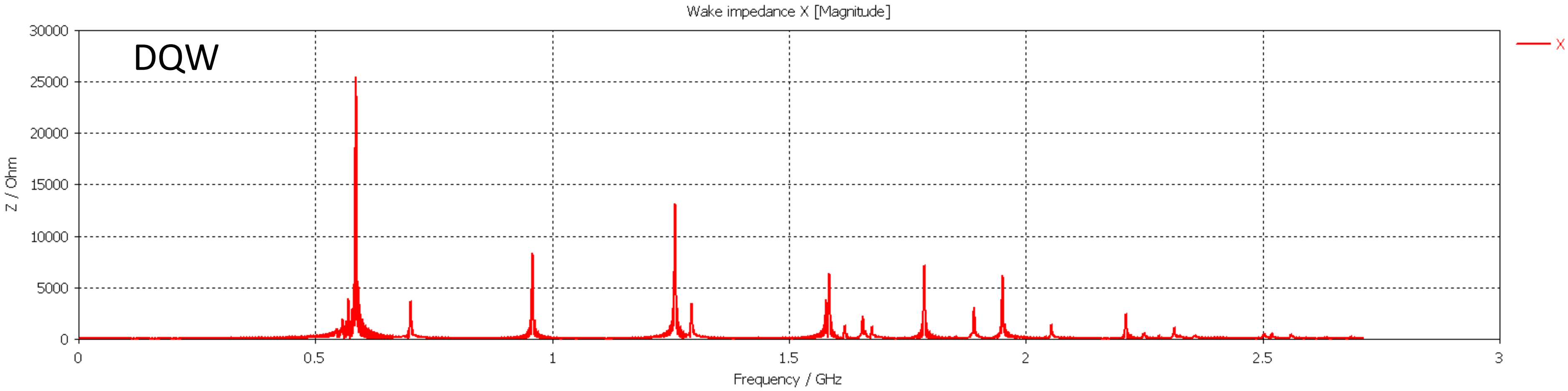
- The new PU has reduced the impedance of the dipole modes at 1.75 GHz below 5 Mohm/m

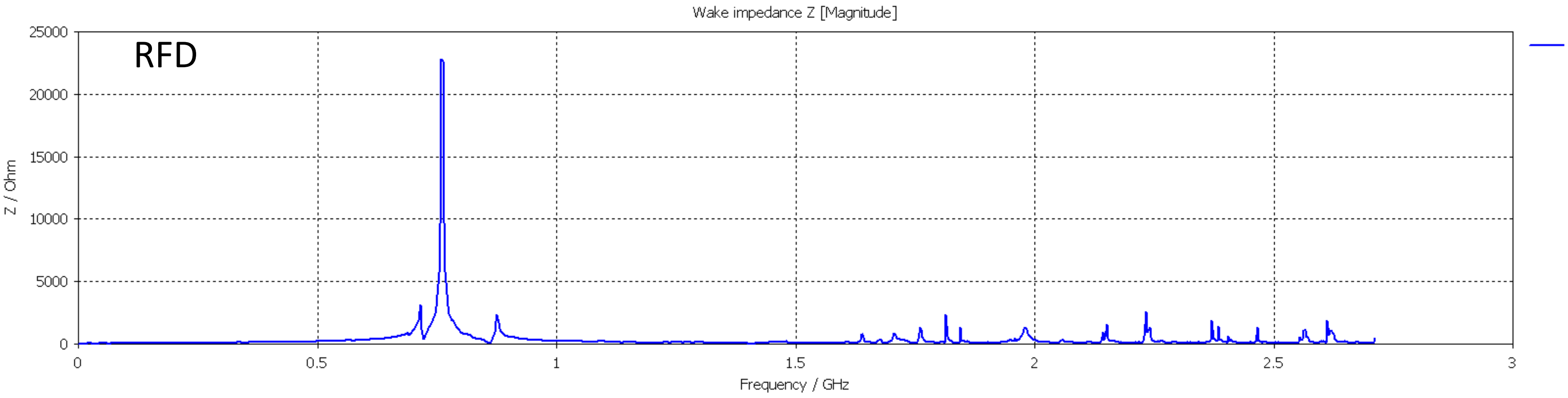




Results courtesy of Binping

Longitudinal Wake Impedance



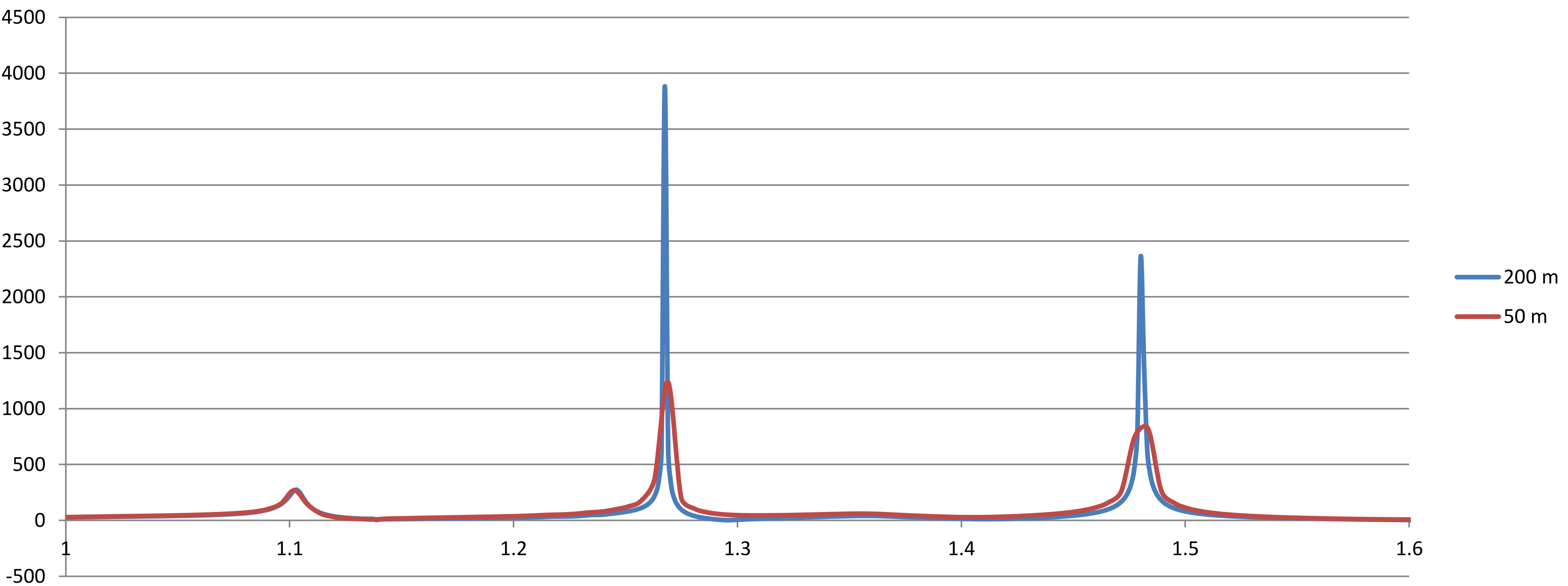


Wakelength

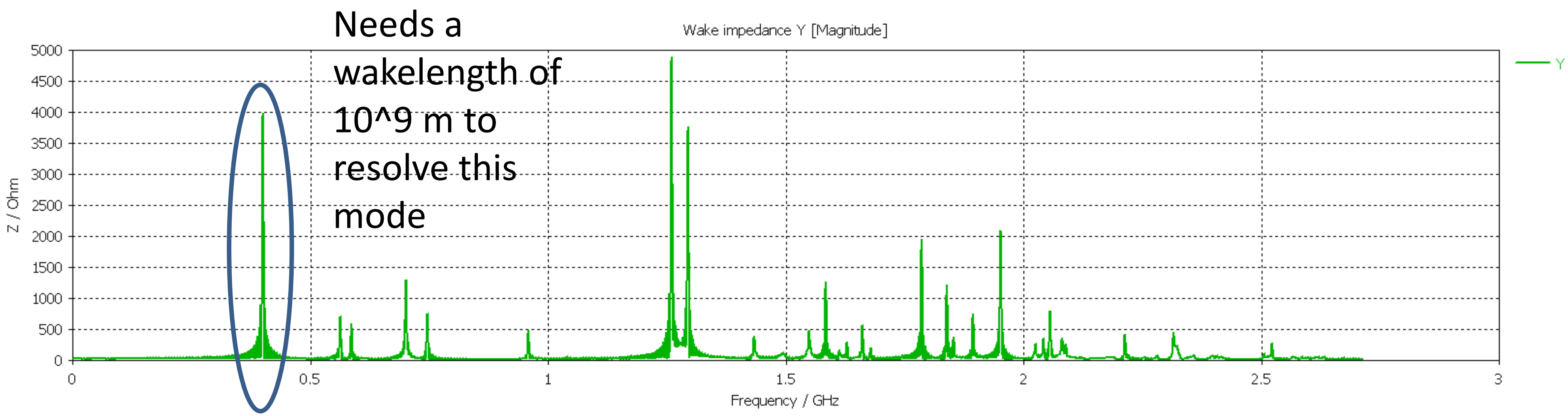
- You can only get a frequency resolution down to Δf (GHz) = 300/s (mm)
- That means that you need a long wakelength to resolve high Q modes (Q=10^6 at 1 GHz requires s=300*Q=$3\text{x}10^8$ mm
- I have ran for $2\text{x}10^5$ mm (6 hour run) so I can only resolve a Q of 660.
- Can use eigenmode calculations to get Q and scale but what's the point in doing that.

Effect of varying Wakelength

- Area under curve (R/Q) is constant but peak height (Z) varies with wakelength.



Wake Impedance in crab plane

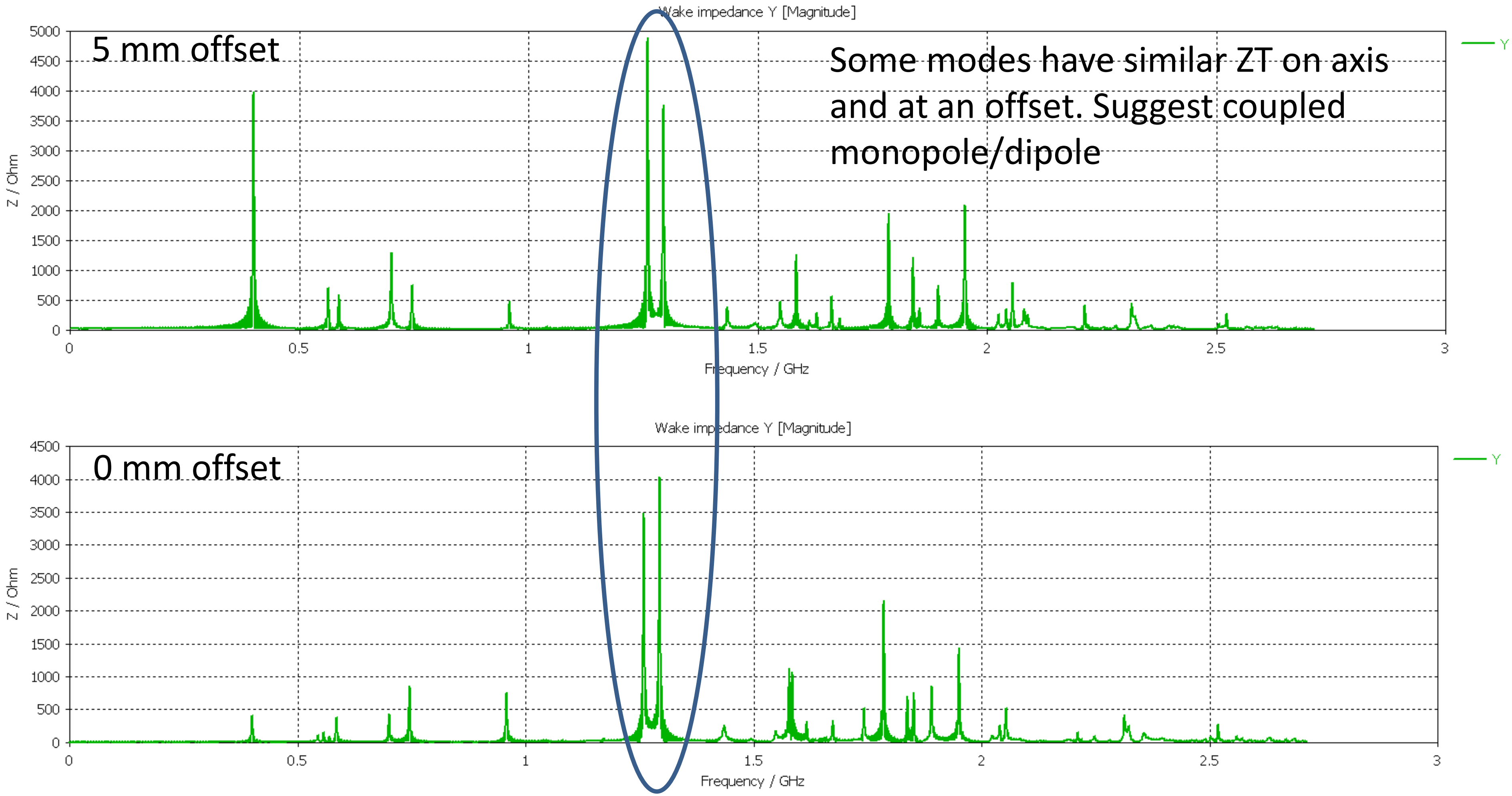


$$W_{\perp}(r_1, s) = -\nabla_{\perp} \int_{-\infty}^{s} ds'\, W_{\parallel}(r_1, s')$$

$$Z_{\perp}(\omega) = i \frac{\int_{-\infty}^{\infty} W_{\perp}(s) e^{-i\omega s} ds}{\int_{-\infty}^{\infty} \lambda(s) e^{-i\omega s} ds}$$

- 1400/5mm =0.28 Mohm/m (note not properly resolved)

Vertical Wake Impedance



Panofsky Wenzel

$$FT\left\{\frac{\partial}{\partial s}\mathbf{W}_{\perp}(r,r_1,s)=-\nabla_{\perp}W_{||}(r,r_1,s)\right\}$$

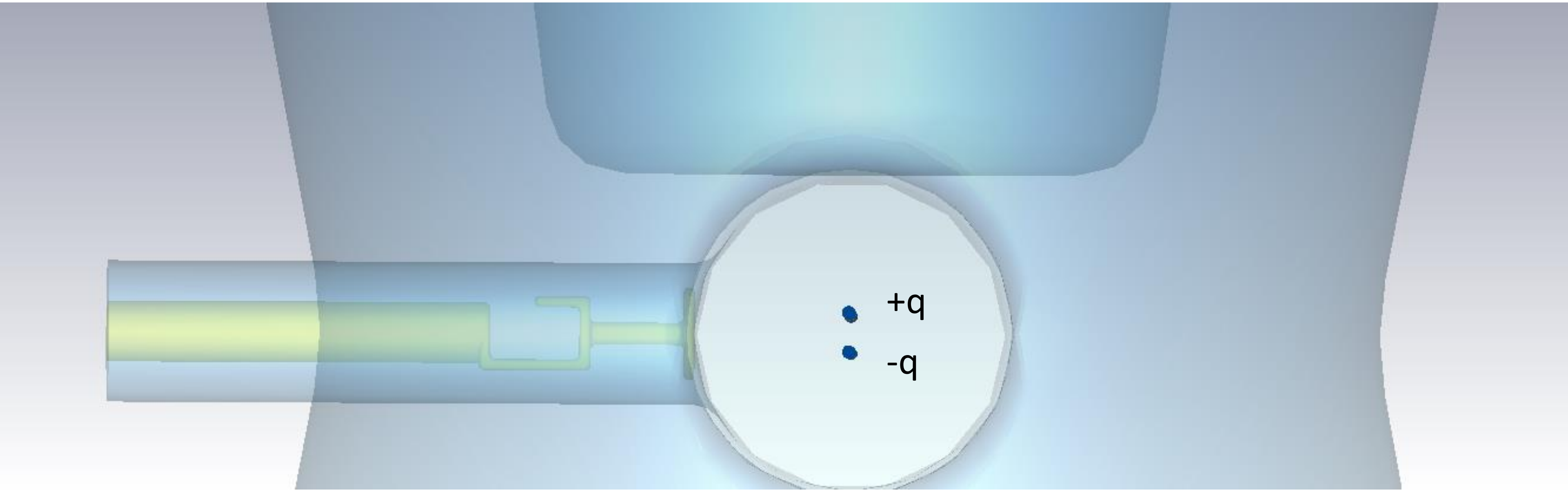
$$\Rightarrow Z_{\perp}(r,r_1;\omega)=-\frac{c}{\omega}\nabla_{\perp}Z(r,r_1;\omega)$$

- The transverse impedance can be found directly from the longitudinal impedance.
- But this only tells us the effect of transverse fields, not if they are monopole ($1-k*r^2$), dipole $r*\cos(\phi)$ or quad $r^2\cos(2*\phi)$.
- Note this is Ohms not Ohm/m, to find that we need to separate dipole terms.
- This makes a huge difference

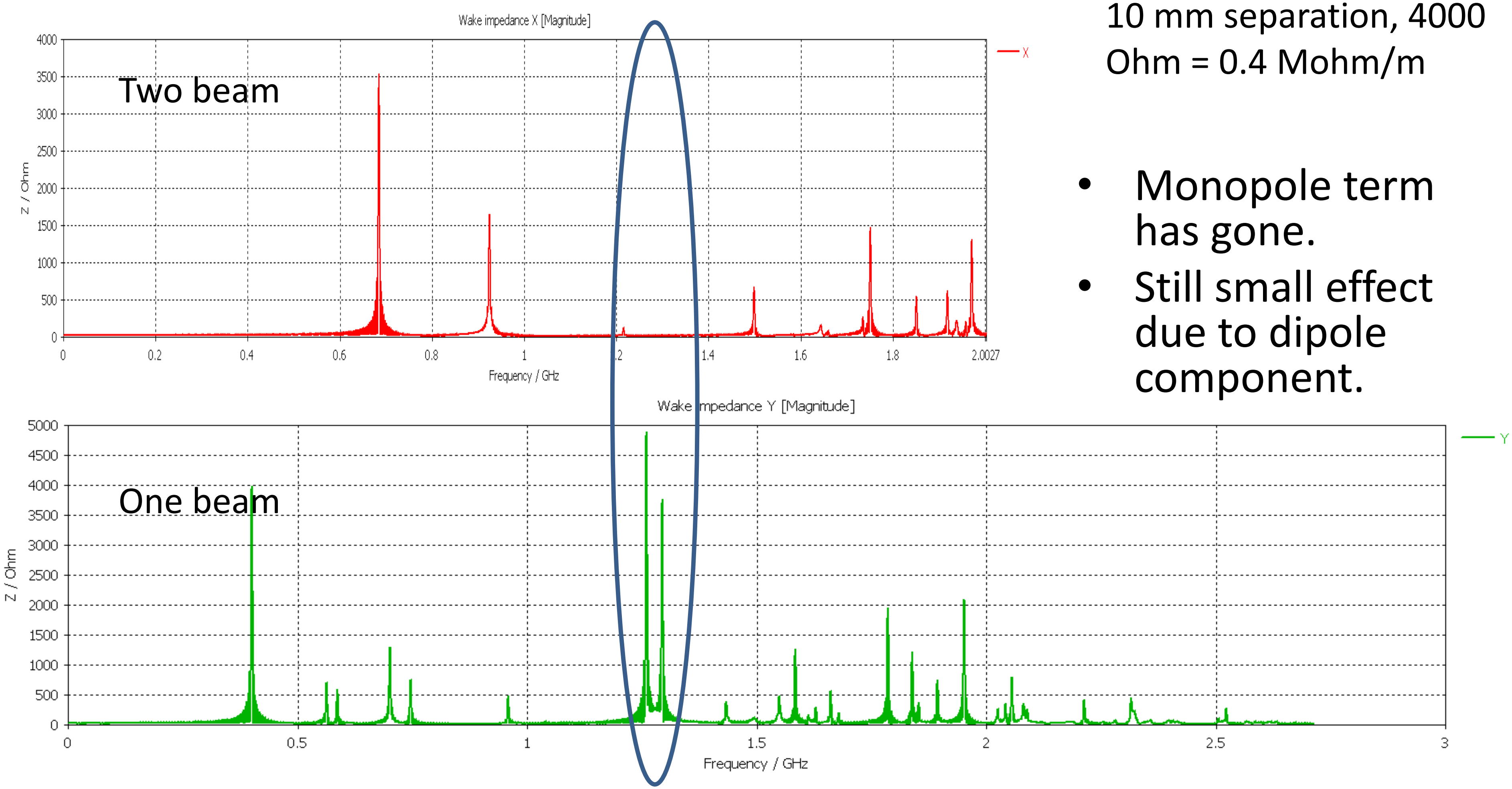
Finding dipole component

- Can we obtain dipole Z_T/m from taking Z_T at two points separated in r?
  - No as the real component is always positive so dipole and quads look the same (doesn't change sign when crossing r=0).
- Panofsky-Wenzel theorem requires knowledge of the multipolar order to find dipole terms so that's no use.
- Could solve at lots of different radii or angles and separate by hand.
- Rama is playing with forcing boundary conditions on axis to remove electrical center offset and solving the cavity in two halves.
- An off-centre quad HAS a dipole component and an off-centre monopole HAS a dipole component.
- Can also use two beams to remove quad component but not sextupole. Using more beams can remove sextupole too.

Two beams



Two beams (note separation is twice as large for two beams)

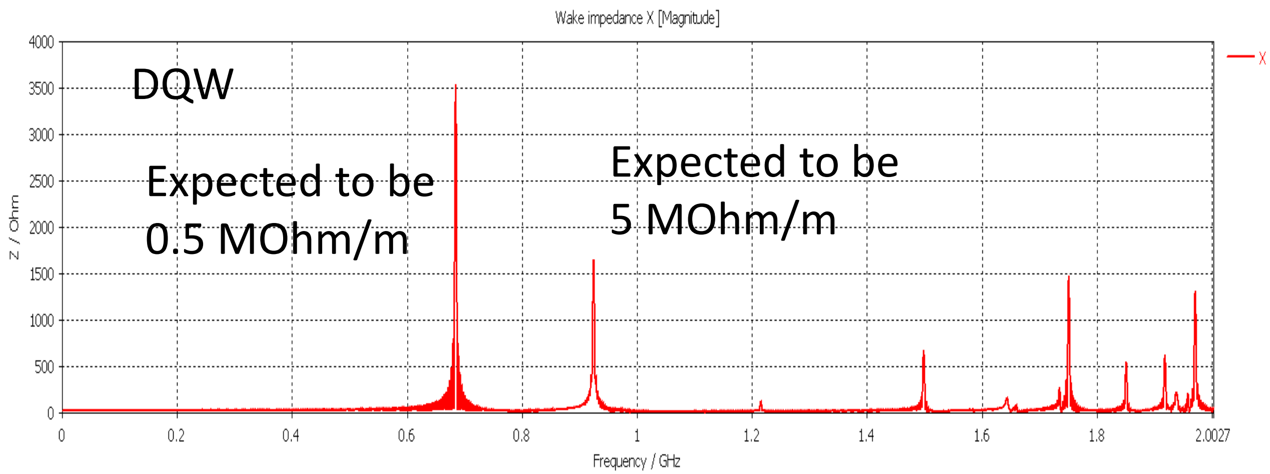


10 mm separation, 4000 Ohm = 0.4 Mohm/m

- Monopole term has gone.
- Still small effect due to dipole component.

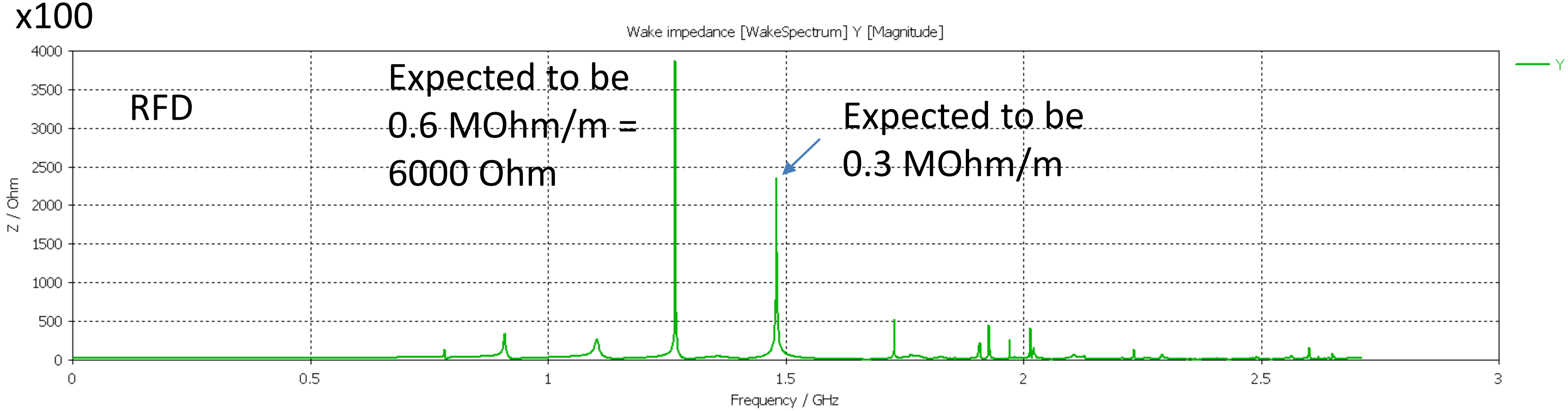
ZT not in plane of crabbing

x100



- Similar impedance but at higher frequency in RFD
- However very few modes resolved

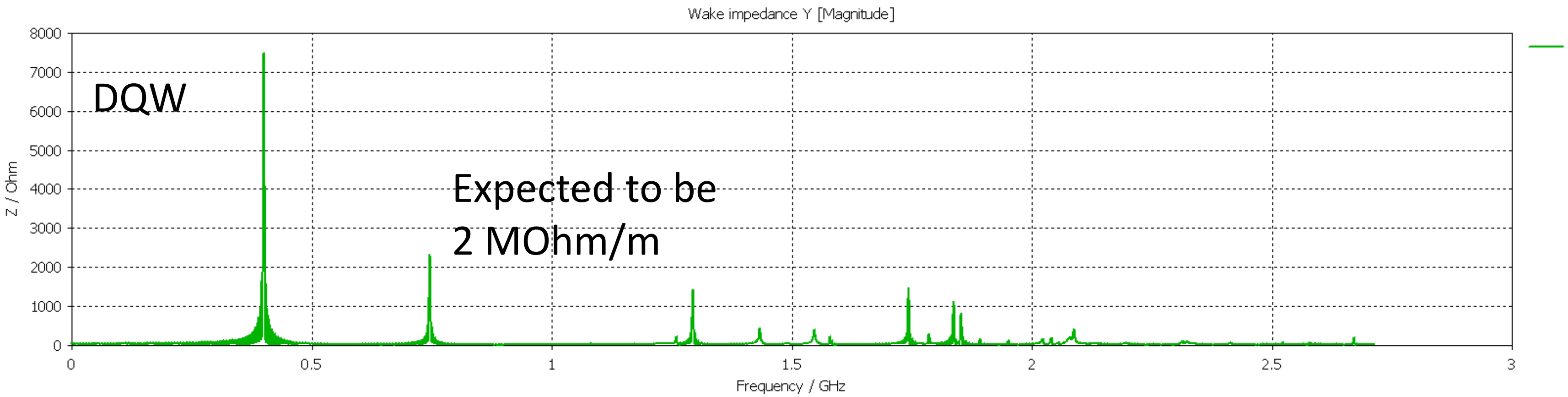
x100



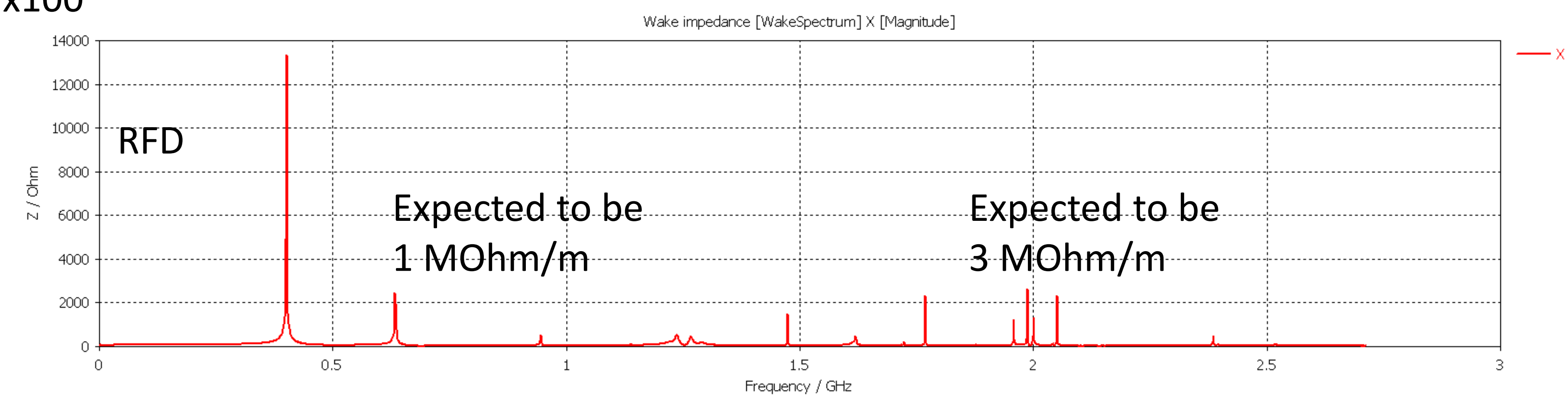
Note: DQW 100 m and RFD 200 m cannot directly compare

ZT in plane of crabbing

x100

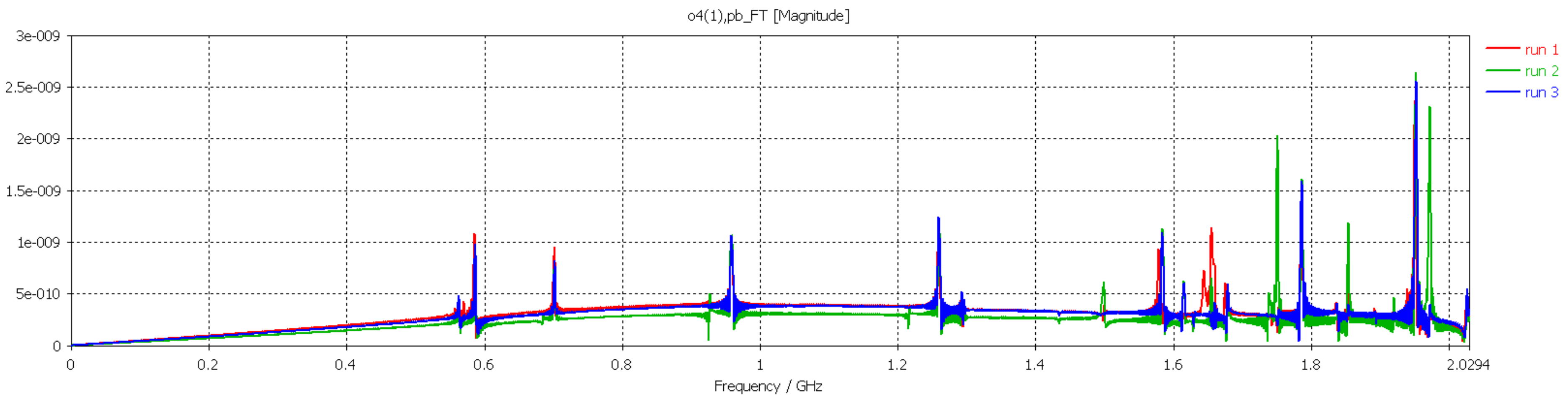


x100



Note: DQW 100 m and RFD 200 m cannot directly compare

Port signal (PU)



- Can find the power through ports which is useful (but limited to single bunch)

Conclusions

- LARP cavity designers have modified HOM couplers and pick-up in order to provide additional damping to a few troublesome modes.
- Impedance is now below 5 MOhm/m, we will hear later from Benoit if this is ok.
- Now looking at direct impedance calculations but it will take a very long time to run.
- Can look at a hybrid method to find Qe and modify spectrum but not clear if this is useful.